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# STRATEGIC AIRLIFT ASSETS OPTIMIZATION MODEL

by

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Despite the outcome of Operation Desert Shield/Storm, post-operation analysis revealed a shortcoming in USAF airlift capability. The analysis showed that early presence was not sustainable and an early Iraqi attack could have inflicted more coalition casualties. This finding prompted Congress to sponsor the Mobility Requirement Study (MRS). This thesis, sponsored by the USAF Studies and Analyses Agency, is an outgrowth of USAF and Joint Staff work for MRS. The thesis develops a multi-period Strategic Airlift Assets Optimization model using linear programming (LP), implemented with the General Algebraic Modelling System (GAMS). The model minimizes late deliveries, subject to constraints such as aircraft utilization rate and aircraft handling capacity of an airfield. This thesis demonstrates that such an LP model has sufficiently fast response time to be a viable planning tool in today's political environment, where major regional conflicts can emerge very quickly. The model can lend support to the study of military options at the planning and acquisition stages, as well as enable planners to quickly assess the impact of any shortfall in airlift capability.

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## ABSTRACT

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## EXECUTIVE SUMMARY

Despite the outcome of Operation Desert Shield/Storm, post-operation analysis revealed a shortcoming in USAF airlift capability. The analysis showed that early presence was not sustainable and an early Iraqi attack could have inflicted more coalition casualties. This finding and the desire to gain insights into the mobility system prompted Congress to sponsor the Mobility Requirement Study (MRS).

This thesis involves an optimization modelling of strategic airlift assets (aircraft and airfields) and is sponsored by the USAF Studies and Analyses Agency. It is an outgrowth of the USAF and Joint Staff work for MRS. The thesis attempts to provide insights into the strategic airlift system. Basically, it attempts to provide answers to airlift mobility questions such as, what are the system "bottle-necks" and which set of alternative strategic airlift fleets is the most effective for the scenario.

In this research, the strategic airlift assets optimization problem is formulated as a multi-commodity, multi-period network flow model with a large number of side constraints using linear programming (LP). The model, implemented on the General Algebraic Modelling System (GAMS), minimizes late deliveries subject to system constraints such as aircraft utilization rate and aircraft handling capacity of an airfield.

This optimization model can provide broad analytic insights into the strategic airlift system. For any particular set of input data, the insights gained include answers to the following mobility questions: 1) Are the assets adequate for the scenario? 2) What are the impacts of a shortfall in airlift capability? 3) What are the system "bottlenecks"?

This thesis demonstrates that such an LP model has sufficiently fast response time to be a viable planning tool in today's political environment, where major regional conflicts can emerge quickly and simultaneously. The model can lend support to the study of military options at the planning and acquisition stages, as well as enable planners to quickly assess the impact of any shortfall in airlift capability.

# I. INTRODUCTION

In October 1993, the Naval Postgraduate School (NPS) Operations Research Department was formally enlisted by the United States Air Force Studies and Analyses Agency (USAF/SAA) to develop a Strategic Airlift Assets optimization model. This model would be used as a planning tool in analyzing mobility questions such as the impact of any shortfall in airlift capability for a particular major regional contingency.

## A. BACKGROUND

Despite the outcome of Operation Desert Shield/Storm, post-operation analysis revealed a shortcoming in USAF airlift capability. The analysis showed that early presence was not sustainable and an early Iraqi attack could have inflicted more coalition casualties. It is for this reason that Congress commissioned a Mobility Requirement Study (MRS) in 1991. This comprehensive study examined all aspects of the mobility question, from domestic transportation to both inter-theater and intra-theater requirements.

Two linear program (LP) optimization models arose directly from the Congressionally-mandated study and form the background of this thesis. They are the Joint Staff's Force Structure Resource, and Assessment Directorate (J8)'s Mobility Optimization Model [Ref. 1] and the USAF Studies and Analyses Agency's Thruput Model [Ref. 2].

### 1. Mobility Optimization Model

The Mobility Optimization Model (MOM), a product of MRS, was developed by J8 with assistance from NPS within a short period of six weeks. MOM was developed to aid in determining the proper level and mix of lift assets (air and sea) necessary to support US power projection needs into the 21st century. Although MOM serves its purpose well, it is not suitable for answering the mobility questions currently sought by USAF/SAA because it does not model airlift constraints in sufficient detail; e.g., the maximum number of planes on the ground (MOG) constraint at intermediate airfields is not directly modelled. Some of MOM's technology has, however, been adopted by this thesis.

### 2. Thruput Model

The static Thruput optimization model was developed by USAF/SAA to help evaluate alternative military strategic airlift fleets, route structures and basing schemes for different scenarios. Although the Thruput model has proven to be useful, it has inherent limitations due to its static nature (single period). For example, important constraints such as delivery time windows cannot be modelled when the time domain is not incorporated. In addition, the model is unable to provide answers to key questions that concern decision makers such as: On what day will *unit x* commence movement and on what day will it be closed?

## B. THESIS GOAL

The goal of this thesis is to develop a multi-period Strategic Airlift Assets LP optimization model using the General Algebraic Modelling System (GAMS) [Ref. 3] for the USAF. This new optimization model is an outgrowth of the USAF and Joint Staff work for MRS. It attempts to combine the best features of both models by retaining Thruput's level of system detail while incorporating MOM's treatment of the time domain. Specifically, the new model strives to provide answers to mobility questions, some of which are not available from existing models. For example:

- Are the given sets of aircraft and airfields adequate for the deployment scenario?
- If the assets are inadequate, what is the impact of the shortfall in terms of tons of equipment and number of men delivered to the theater late?
- Which of the assets (aircraft or airfield) are "bottle-necks" in the system? Is there a need to increase the number of aircraft (reserves or civilian aircraft) or a need to negotiate for access to more foreign airfields?
- Which set of alternative strategic airlift fleets is the most effective for the scenario?
- On what day will unit *x* commence movement and on what day will it be closed?

## C. PROBLEM STATEMENT

The precise nature of the airlift problem is: Given the movement requirements for both troops and equipment for a particular scenario, and the aircraft and airfield assets available, find the optimal combination of airlift mission assignments by number and type of aircraft for each unit, routing structure, airlift mission start time and cargo type to carry. The objective of the model is to minimize penalties (weighted by each unit's

priority) for late deliveries and undelivered cargo, subject to system constraints such as bounds on aircraft utilization rates and the aircraft handling capacity of each airfield.

## D. JUSTIFICATION FOR MODEL

The justifications for developing the Strategic Airlift Assets optimization model are the need to optimize and the need for quick answers.

- Need to optimize: With shrinking military budgets, the number of both aircraft and airfields available are set to decline. Further, the desire to have early force closure so as to reduce the vulnerability period when US forces may be outnumbered imposes great strains on the mobility system. These two factors imply that inevitably, demand will exceed supply and there is a need to optimally utilize both aircraft and airfield assets.

- Need to have quick answers: Today's political environment has great uncertainties in which a major regional conflict can emerge very quickly (for example Somalia). In this respect, an optimization model such as the strategic airlift model which has good turnaround time would be a viable and useful planning tool.[1] In fact, its quick turnaround time may allow the optimization model to be used in a complementary manner with other models which have different virtues; e.g., a simulation model can capture more detail but generally takes longer to run. One possible complementary mode of operation is to use the outputs of the optimization model as inputs for the simulation model, e.g., number of aircraft and airfield assets to use.

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[1]The current optimization model has a total response time of under 2 hrs for a typical size problem. It takes approximately an hour and a half to enter new data and the LP is generated and solved in under 2 minutes on an IBM RS6000 model 590 workstation.

# II. OVERVIEW OF MODEL

This chapter gives a broad overview of pertinent features of the airlift system, modelling assumptions, and a verbal description ("word formulation") of the objective function and constraints. Also included in this chapter is a brief discussion on the origin of data sources, the need for data aggregation and model reduction techniques.

## A. MODEL FEATURES

The airlift system has its own peculiar features and modes of operation. Most of these have been incorporated in the model to make it as representative of real time operation as possible. Others, such as the use of tanker aircraft for aerial refueling of airlift aircraft are recommended as follow-on work. One possible way to incorporate the use of tankers is the "airbase in the sky" concept utilized by RAND's CONOP optimization model [Ref. 4]. The major aspects of the airlift system captured by the model include:

- Multiple origin/destination airfields (source and sink nodes): This feature is representative of the airlift system that typically utilizes multiple origin, enroute and destination airfields. The model can facilitate the study of simultaneous major regional contingency plans.

- Flexible routing structure: The air route structure supported by the model includes delivery/recovery routes with zero to three enroute stops. This provision allows for use of a mixture of both short-range and long-range aircraft. It also allows the LP to choose between higher-payload, shorter-range flights (more enroute stops and more ground time) and lower-payload, longer-range flights. In addition to the variable number of enroute stops, the model also allows the same aircraft to fly different delivery and recovery routes for improved realism and efficiency.

- Aircraft-to-route restriction: Provisions have been made to allow the user to impose aircraft-to-route restrictions; e.g., military aircraft may use military airfields for enroute stops. This particular provision arises because Air Mobility Command (AMC) may rely on civilian airliners to augment USAF aircraft in a deployment under the Civil Reserve Airfleet (CRAF) program. It is necessary to distinguish between the USAF and CRAF aircraft because of possible route restrictions. For example, military aircraft may not be permitted to land in certain civilian airfields. The model also allows the user to route aircraft through specific recovery bases, as in AMC's typical concept of operations.

- Aircraft assets can be added over time: This adds realism to the model since CRAF and reserves aircraft typically take time to mobilize and are generally not available until later in the deployment.

- Delivery time windows: In a deployment, a unit is ready to move on a certain date and has to arrive at the theater by a specific date; i.e., there is a Time Phase Force Deployment Date (TPFDD) associated with each unit. This aspect of the problem has been incorporated in the model through user-specified dates for each unit.

## B. ASSUMPTIONS

Listed below are the major assumptions made by the model. These assumptions are made due to the nature of the data available or to avoid computational intractability.

- Inventoried aircraft at origin/destination airfields do not affect the aircraft handling capacity of the airfield: This assumption is made in the modelling of the aircraft handling capacity constraint of each airfield. It is not strictly valid since an inventoried aircraft takes up parking space even if it is not consuming services. However, since the aircraft handling capacity figures are based on a host of other factors like material handling equipment (MHE), servicing and fuel availability, it is probably more accurate to model the problem as such. Segregation of airfield capacity data (into parking spaces and services) is necessary before the constraints can be modelled appropriately. This recommendation has been made to the USAF.

- Deterministic ground time: Aircraft turnaround times for onload/offload of cargo and enroute refuelling are assumed to be known constants, although they are naturally stochastic. This assumption will result in an optimistic solution from the LP as time deviations could cause some aircraft to wait on the ground while others are being serviced. The stochastic nature of ground time is however, offset

somewhat by a MOG efficiency factor introduced in the formulation to soften the impact of randomness. Further research and validation are required to assess the impact of this assumption and the offsetting technique.

- No restriction on airfield operating hours: The assumption that all airfields are twenty-four hour capable is included as a caveat for future modelers because an airfield may have operating hours restriction. Airfield operating hours do not affect the current model since the time resolution (in days) does not warrant a discrimination of airfield operating hours as arrivals at each airfield is rounded to the nearest day; i.e., no distinction between day and night arrival etc. Airfield operating hours may become important if the time resolution of the model is reduced to say six hour blocks.

## C. "WORD FORMULATION"

This section gives a verbal description of the objective function and constraints of the Strategic Airlift Assets optimization model. Discussions on the mathematical formulation and implementation details can be found in Chapters III and IV respectively.

### 1. Objective Function

The purpose of the optimization model is to determine a schedule of airlift missions with troops and cargo to carry, and recovery missions, so as to minimize the total weighted penalties of late deliveries and undelivered cargo (weighted by the movement priority of a unit).

### 2. Constraints

The constraints of the airlift system modelled can be broadly grouped into the following categories: Demand satisfaction, aircraft balance, aircraft physical limitation, aircraft utilization rate and aircraft handling capacity of an airfield.

- Demand Satisfaction Constraints: Demands on the airlift system are the movement requirements for troops and cargo. The demand satisfaction constraints for troops try to ensure that the number of troops that arrive within the permitted time window for each unit is greater than the number required, with shortfalls accounted for by deviation variables that are penalized in the objective function. The demand satisfaction constraints for each unit's cargo serve the same purpose for the required equipment.

- Aircraft Balance Constraints: These constraints keep physical count of aircraft by type in each time period. They ensure that the aircraft assets are used only if and when they are available.

- Aircraft Physical Limitation Constraints: There are three different kinds of constraints on the physical limitations of aircraft. These constraints ensure that limits on troop carriage capacity, maximum payload, and cabin floor space constraints are observed at all times.

- Aircraft Utilization Rate Constraints: These constraints ensure that the average flying hours consumed per aircraft per day is less than AMC's established utilization rate for each aircraft type.

- Aircraft Handling Capacity of Airfield (MOG): These constraints ensure that the number of aircraft routed through an airfield each day can be handled by the airfield.

## D. DATA SOURCES, AGGREGATION AND MODEL REDUCTION

### 1. Data Sources

The data inputs used in trial runs of the model to date were obtained through the assistance of USAF/SAA. Most of these data are scenario-specific and can be found in documents and planning guides.

For example, the airfields' aircraft handling capacity figures (or MOG figures) were developed by AMC for the Mobility Requirements Study and data such as

space or maximum payload of an aircraft for a particular range were obtained from aircraft technical manuals. Appendix A gives a listing of the data sources.

### 2. Data Aggregation

The need for data aggregation as well as efficient handling of multi-dimensional modeling entities was envisaged early during model development. For example, there is a set of decision variables with eight indices that would have over 9 millions members if all combinations are included.[2] This set must be reduced drastically in model implementation in order for the LP to be tractable. For this reason, the geographic and requirements data were reviewed thoroughly with USAF/SAA and aggregated whenever reasonable to do so. For example, airfields in close proximity (up to about 300 nautical miles) are collapsed into a single entity with their MOG figures aggregated, and units with similar origins, destinations and time windows are represented as aggregate movement requirements.

### 3. Model Reduction

In addition to data aggregation, logical conditional checks are used extensively in the model to reduce the number of decision variables. The conditional checks serve to eradicate those combination of decision variables that are known to have zero values at optimality and hence help to reduce the problem size. For a simple example, if there are no Boeing 747 aircraft (CRAF) available until day 10, then all

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[2]The variable has one index each for unit, time period and aircraft type, and 5 indices representing airfields along a route. For a problem with 30 time periods, 20 units, 5 aircraft types and 5 members per airfield index, with all possible index combinations counted, there would be 9,375,000 variables.

airlift missions associated with the B747 fleet for the first 9 days are removed from the LP formulation. Unnecessary constraints are eliminated in a similar manner.

These logical checks and reductions are implemented in a generic fashion, so in contrast to the aggregations they do not have to be reconsidered when the user changes the data.

# III. OPTIMIZATION MODEL

This chapter gives a mathematical formulation of the conceptual optimization model discussed in Chapter II. Implementation aspects of the model are covered in Chapter IV.

## A. METHODOLOGY

The strategic airlift assets optimization problem is basically formulated as a multi-commodity, multi-period network flow model with a large number of side constraints. Two key concepts are employed in the model. The first key concept is the use of a time index to track the locations of aircraft for each time period. Knowing when an aircraft will arrive at a particular airfield allows the aircraft handling capacity constraint of an airfield to be modelled appropriately. The second key concept is model reduction through data aggregation and the removal of unnecessary decision variables and constraints prior to LP optimization.

## B. MATHEMATICAL FORMULATION

### 1. Indices

| | |
|---|---|
| u | unit; e.g., 82nd Airborne |
| a | aircraft type; e.g., C5, C141 |
| t,t' | time period in days |
| b | generic airfield; i.e., origin, enroute and destination airfields |
| i | origin airfield |
| k | destination airfield |
| r | route |

## 2. Index Sets

### a. *Airfield Index Sets*

| | |
|---|---|
| $B$ | set of available airfields |
| $I \subseteq B$ | origin airfields |
| $K \subseteq B$ | destination airfields |

### b. *Aircraft Index Sets*

| | |
|---|---|
| $A$ | set of available aircraft types |
| $A_{bulk} \subseteq A$ | aircraft capable of hauling bulk-sized cargo |
| $A_{over} \subseteq A_{bulk}$ | aircraft capable of hauling over-sized cargo |
| $A_{out} \subseteq A_{over}$ | aircraft capable of hauling out-sized cargo |

### c. *Route Index Sets*

| | |
|---|---|
| $R$ | set of available routes |
| $R_a \subseteq R$ | permissible routes for aircraft *a* |
| $R_{ab} \subseteq R$ | permissible routes for aircraft *a* that utilizes airfield *b* |
| $R_{aik} \subseteq R$ | permissible routes for aircraft *a* that connect the *(i,k)* origin-destination pair |
| $DR_i \subseteq R$ | delivery routes that originate from origin *i* |
| $RR_k \subseteq R$ | recovery routes that originate from destination *k* |

### d. *Time Index Sets*

| | |
|---|---|
| $T$ | set of time periods |
| $T_{uar} \subseteq T$ | permissible delivery window for unit *u* with aircraft *a* and route *r* combination; this time window covers the period from the unit is Available-to-Load Date to the Required Delivery Date plus a maximum allowed lateness for delivery |

## 3. Data

### a. *Movement Requirement Data*

| | |
|---|---|
| $MovePAX_{uik}$ | Troop movement requirement for unit *u* from origin *i* to destination *k* |

$MoveUE_{uik}$ Equipment movement requirement in tons for unit $u$ from origin $i$ to destination $k$

$ProBulk_u$ Proportion of unit $u$ cargo that is bulk-sized (loose cargo palletized on a 88" x 108" platform)

$ProOver_u$ Proportion of unit $u$ cargo that is over-sized (non-palletized cargo rolling stock that can fit into a C141); over-sized cargo has a larger dimension than bulk-sized cargo

$ProOut_u$ Proportion of unit $u$ cargo that is out-sized (non-palletized cargo that can fit into a C5 or C17 but not a C141)

### *b. Penalty Data*

$LatePenUE_u$ Lateness penalty (per ton per day) for unit $u$ equipment

$LatePenPAX_u$ Lateness penalty (per soldier per day) for unit $u$ troops

$NoGoPenUE_u$ "Non-delivery" penalty (per ton) for unit $u$ equipment

$NoGoPenPAX_u$ "Non-delivery" penalty (per soldier) for unit $u$ troops

MaxLate Maximum allowed lateness (in days) for delivery

### *c. Cargo Data*

$UESqFt_u$ Average cargo floor space (in sq. ft.) per ton of unit $u$ equipment

PAXWt Average weight of a soldier inclusive of personal equipment

### *d. Aircraft Data*

$Supply_{at}$ Additional number of aircraft $a$ made available on day $t$

$MaxPAX_a$ Maximum troop carriage capacity of aircraft $a$

$PAXSqFt_a$ Average cargo space (in sq. ft.) consumed by a soldier for aircraft $a$

$ACSqFt_a$ Cargo floor space (in sq. ft.) of aircraft $a$

$LoadEff_a$ — Cargo space loading efficiency for aircraft *a*

$URate_a$ — Established utilization rate (flying hours per aircraft per day) for aircraft *a*

$EffTime_t$ — Number of effective time periods for an aircraft that is available from time period *t*; $EffTime_t = T - t + 1$ where T is the time horizon

### e. *Airfield Data*

$MOGCap_b$ — "Maximum On Ground" capacity for narrow-body aircraft at airfield *b*

$MOGReq_{ab}$ — Normalized MOG requirement (to narrow-body aircraft) for aircraft *a* at airfield *b*. Normalization is required for comparison purposes since an airfield has different MOG figures for each aircraft type (body type); i.e., an airfield can accommodate different number of each type of aircraft (or combinations)

MOGEff — MOG efficiency factor; introduced as a discount factor as it is impossible to fully utilize the MOG capacity due to the stochastic nature of aircraft ground time

### f. *Aircraft Route Performance Data*

$MaxLoad_{ar}$ — Maximum payload (in tons) for aircraft *a* flying route *r*.

$DGTime_{abr}$ — Aircraft ground time (due to onload of cargo, enroute refuelling, maintenance, etc) for aircraft *a* at airfield *b* on delivery route *r*

$RGTime_{abr}$ — Aircraft ground time taken by aircraft *a* at airfield *b* on recovery route *r*

$DTime_{abr}$ — Cumulative time (flight time plus ground time) taken by aircraft *a* to reach airfield *b* along delivery route *r*

$RTime_{abr}$ — Cumulative time (flight time plus ground time) taken by aircraft *a* to reach airfield *b* along recovery route *r*

$FltTime_{ar}$ — Total flying hours consumed by aircraft *a* on route *r*

$DaysLate_{uart}$ — Number of days late (after required delivery date) in delivering unit $u$ requirement using aircraft $a$ flying route $r$ with mission start time $t$; $DaysLate_{uart}$ is equal to zero if the cargo/troops arrive at the destination before (or on) the required delivery date

### 4. Decision Variables

$X_{uart}$ — Number of aircraft $a$ that airlift unit $u$, via route $r$ with mission start time $t$

$Y_{art}$ — Number of aircraft $a$ that recover from a destination airfield via route $r$ with start time $t$

$Allot_{ait}$ — Additional number of aircraft $a$ available from day $t$ that are allocated to origin $i$

$H_{ait}$ — Number of aircraft $a$ inventoried at origin $i$, at time $t$

$HP_{akt}$ — Number of aircraft $a$ inventoried at destination $k$, at time $t$

$TonsUE_{uart}$ — Total tonnage of unit $u$ equipment airlifted by aircraft $a$, via route $r$ with mission start time $t$

$TPAX_{uart}$ — Total number of unit $u$ troops airlifted by aircraft $a$, via route $r$ with mission start time $t$

$UENoGo_{uik}$ — Total tonnage of unit $u$ equipment not airlifted from origin $i$ to destination $k$ in the prescribed time frame

$PAXNoGo_{uik}$ — Number of unit $u$ troops that not airlifted from origin $i$ to destination $k$ in the prescribed time frame

### 5. Objective Function

The model objective is to minimize the total weighted penalties (weighted by the movement priority of a unit) for late deliveries and undelivered cargo and troops. The objective function value, z, is given by:

*Minimize Z* =

$$\sum_{u}\sum_{a}\sum_{r\in R_a}\sum_{t\in T_{uar}} (LatePenUE_u * DaysLate_{uart}) * TonsUE_{uart}$$

$$+ \sum_{u}\sum_{a}\sum_{r\in R_a}\sum_{t\in T_{uar}} (LatePenPAX_u * DaysLate_{uart}) * TPAX_{uart}$$

$$+ \sum_{u}\sum_{i}\sum_{k} (NoGoPenUE_u * UENoGo_{uik}) + (NoGoPenPAX_u * PAXNoGo_{uik}).$$

There are two reasons for including a "undelivered" cargo category in the objective function. First, it allow the user to control the number of time periods. Second, it permits situations where the movement requirements cannot be fulfilled due to limited aircraft, airfields, and time horizon; i.e., it allows the LP model to produce a feasible solution even when available assets are inadequate.

Some care must be taken in determining late and non-delivery penalties to ensure that they are on a common basis of *x* tons of one unit versus *x* tons of another. In addition, the user should ensure that weights are consistent; i.e., late delivery should be preferred to non-delivery. The weights will be consistent provided a late penalty (per ton per day) is less the corresponding non-delivery penalty (per ton) divided by the maximum allowed lateness (in days) for delivery.

### 6. Constraints

The objective function is subject to the following constraints.

#### *a. Demand Satisfaction Constraints*

Demands on the airlift system are the movement requirements for troop and different classes of cargo (bulk, over and out-sized). There are four different kinds

of demand satisfaction constraints (one for troops and three for cargo). Three separate constraints are required for cargo due to the need to impose upper bounds on the amount of cargo that can be carried by a particular class of carrier (e.g., over-sized cargo carrier); this ensures cargo-carrier compatibility.

The demand satisfaction constraints for troops ensure that the number of troops airlifted within the permitted time window for each unit is greater than or equal to the number required, with the shortfalls accounted for in the deviation variables (PAXNoGo). The demand satisfaction constraints for each unit's cargo serve the same purpose for the required equipment. The demand satisfaction constraints follow:

*(1) Demand Satisfaction Constraints for All Classes of Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment delivered to the theater by all aircraft types (over all permissible aircraft, route and mission start time combination) plus total tonnage not delivered (UENoGo) must be greater than or equal to the movement requirement for equipment:

$$\sum_{a \in A_{bulk}} \sum_{r \in R_{aik}} \sum_{t \in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq MoveUE_{uik} \quad \forall \quad u,i,k : MoveUE_{uik} > 0.$$

*(2) Demand Satisfaction Constraints for Out-Sized Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment carried by out-sized cargo capable aircraft plus the total tonnage not delivered must be greater than or equal to the movement requirement for out-sized cargo (given by proportion of out-sized cargo multiplied by movement requirement for equipment):

$$\sum_{a \in A_{out}} \sum_{r \in R_{aik}} \sum_{t \in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq ProOut_u * MoveUE_{uik}$$

$$\forall \quad u,i,k : MoveUE_{uik} > 0.$$

*(3) Demand Satisfaction Constraints for Over-Sized Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment carried by over-sized cargo capable aircraft plus the total tonnage not delivered must be greater than or equal to the movement requirement for over-sized and out-sized cargo:

$$\sum_{a \in A_{ovr}} \sum_{r \in R_{aik}} \sum_{t \in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq (ProOver_u + ProOut_u) * MoveUE_{uik}$$

$$\forall \quad u,i,k : MoveUE_{uik} > 0.$$

The right-hand-side of the constraint is valid because out-sized cargo capable carriers are also over-sized cargo capable.

*(4) Demand Satisfaction Constraints for Troops.* For each unit and associated origin-destination pair, the total number of troops airlifted to the theater plus those not airlifted must be greater than or equal to the movement requirement for troops:

$$\sum_{a} \sum_{r \in R_{aik}} \sum_{t \in T_{uar}} TPAX_{uart} + PAXNoGo_{uik} \geq MovePAX_{uik} \quad \forall \; u,i,k : MovePAX_{uik} > 0.$$

### *b. Aircraft Balance Constraints*

The number of aircraft $a$ assigned for airlift missions (or to be recovered from a destination airfield) must be no more than the number of aircraft $a$ available for use. The three different kinds of aircraft balance constraints are:

*(1) Aircraft Balance Constraint at Origin Airfield.* For each aircraft $a$, origin $i$ and time period $t$ combination, the total number of aircraft assigned for airlift missions, plus those inventoried for later use must be equal to the total number of aircraft available from the previous period plus new supply of aircraft allocated to the origin and returns from previous missions:

$$\sum_{u} \sum_{r \in DR_i} X_{uart} + H_{ait} = H_{ai(t-1)} + Allot_{ait} + \sum_{r \in R_a} \sum_{t' + RTime_{air} = t} Y_{art'} \qquad \forall \quad a,i,t.$$

*Note*: $H_{ai(t-1)}$ *is only defined for* $t$ *greater than* 1.
$X_{uart}$ *is only defined for* $t \in T_{uar}$.

*(2) Balance Constraint for Aircraft Allocation.* The total number of aircraft $a$ allocated to the different origin airfields in each time period $t$ must not be greater than the new supply of aircraft $a$. This constraint is incorporated in the model as it is more efficient for the LP model to distribute the new supply of aircraft than for a user to predetermine the allocation:

$$\sum_{i} Allot_{ait} \leq Supply_{at} \qquad \forall \quad a,t : Supply_{at} > 0.$$

*(3) Aircraft Balance Constraint at Destination Airfield.* For each aircraft $a$, destination $k$ and time period $t$ combination, the total number of aircraft $a$ recovering from the destination airfield this period plus those that are to be inventoried must be equal to those waiting to return (inventory from last period) plus new arrivals at the destination:

$$\sum_{r \in RR_k} Y_{art} + HP_{akt} = HP_{ak(t-1)} + \sum_{u} \sum_{r \in R_a} \sum_{\substack{t' \in T_{uar} \\ t' + DTime_{akr} = t}} X_{uart'} \quad \forall \quad a,k,t.$$

*Note*: $HP_{ak(t-1)}$ *is only defined for* $t$ *greater than* 1.

### c. *Aircraft Physical Limitation Constraints*

There are three different kinds of constraints on the physical limitations of aircraft. These constraints ensure that limits on troop carriage capacity, maximum payload, and cargo floor space are observed.

*(1) Troop Carriage Capacity Constraints.* The total number of troops airlifted for each unit $u$, aircraft $a$, route $r$, and mission start time $t$ combination must not be greater than the troop carriage capacity of aircraft $a$ multiplied by the number of aircraft $a$ assigned:

$$TPAX_{uart} \leq MaxPAX_a * X_{uart} \qquad \forall \qquad u,a,r,t : t \in T_{uar}.$$

*(2) Maximum Payload Constraints.* The total payload (equipment and troops) airlifted for each unit $u$, aircraft $a$, route $r$, and mission start time $t$ combination must not be greater than the maximum payload for aircraft $a$ flying route $r$, multiplied by the number of aircraft $a$ assigned:

$$TonsUE_{uart} + (PAXWt * TPAX_{uart}) \leq MaxLoad_{ar} * X_{uart} \quad \forall \quad u,a,r,t : t \in T_{uar}.$$

*(3) Cargo Floor Space Constraints.* The total floor space taken up by troop and equipment for each unit $u$, aircraft $a$, route $r$, and mission start time $t$

combination must not be greater than the aircraft cargo floor space multiplied by the loading efficiency factor and number of aircraft $a$ assigned:

$$(PAXSqFt_a * TPAX_{uart}) + (UESqFt_u * TonsUE_{uart}) \leq ACSqFt_a * LoadEff_a * X_{uart}$$

$$\forall \quad u,a,r,t : t \in T_{uar}.$$

### *d. Aircraft Utilization Rate Constraints*

These constraints ensure that the average flying hours consumed per aircraft per day is less than AMC's established utilization rate for each aircraft type; the upper bounds for aircraft utilization is designed to capture spares availability, aircraft reliability, crew availability, etc.

Aircraft utilization rate constraints are modelled by comparing the actual flying hours consumed by an aircraft fleet in a deployment with the maximum achievable flying hours for the fleet based on the utilization rate. The total flying hours consumed by an aircraft fleet in a deployment is equal to the total flying hours consumed for both delivery and recovery routes. The maximum achievable flying hours is given by the utilization rate multiplied by the productive time periods of each available aircraft.

$$\sum_{u} \sum_{r \in R_a} \sum_{t \in T_{uar}} (FltTime_{ar} * X_{uart}) + \sum_{r \in R_a} \sum_{t} (FltTime_{ar} * Y_{art})$$

$$\leq \sum_{t:Supply_{at}>0} URate_a * EffTime_t * Supply_{at} \qquad \forall \quad a.$$

As a simple illustration for the above equation, consider a fleet of 5 aircraft made available from day 11. If the utilization rate for this aircraft type is 10 flying hours per aircraft per day and the time window of concern is 30 days, then the

maximum achievable flying hours for the aircraft type over the time period is 1000 (10 x 20 x 5). This total must not be exceeded by the actual flying hours consumed by the aircraft fleet over the same period.

#### *e. Aircraft Handling Capacity of Airfield (MOG Constraint)*

These constraints model the aircraft handling capacity or throughput of each airfield. They ensure that the LP does not route more aircraft through an airfield than it can handle each day.

The maximum number of aircraft an airfield can handle each day depends on the following factors: MOG capacity of the airfield which gives the maximum number of aircraft it can accommodate at any one time, aircraft body type (narrow-body, wide-body, etc) and the amount of time each aircraft spends at the airfield.

Aircraft handling capacity constraints are modelled by computing the total MOG consumed (normalized to that of a narrow-body aircraft) in each period by each individual aircraft using the airfield. This total should not exceed the normalized MOG capacity of the airfield discounted by a MOG efficiency factor. The MOG efficiency factor is introduced as the stochastic nature of aircraft ground time implies that it is impossible to fully utilize the airfield. It is recognized that deviations from scheduled ground times can cause some aircraft to wait on the ground (or conceivably in the air) while others are being serviced. The MOG consumed by an aircraft is equal to its normalized MOG requirement multiplied by the ratio of time spent (in hours) under service to number of hours in a time period. The equation follows:

$$\sum_{u} \sum_{a} \sum_{r \in R_a} \sum_{\substack{t' \in T_{uar} \\ t' + DTime_{abr} = t}} (MOGReq_{ab} * DGTime_{abr} / 24) * X_{uart'}$$

$$+ \sum_{a} \sum_{r \in R_a} \sum_{t' + RTime_{abr} = t} (MOGReq_{ab} * RGTime_{abr} / 24) * Y_{art'}$$

$$\leq MOGEff * MOGCap_b \qquad \forall \quad b,t.$$

As a simple illustration for the MOG constraint, consider the case of an airfield that can handle 10 narrow-body aircraft at a time and a MOG efficiency factor of 0.8. If each narrow-body aircraft spends 3 hours on the ground, then over the whole period (day), the airfield would be able to handle 64 narrow-body aircraft; i.e., as the equation implies 1 x 3/24 x 64 = 0.8 x 10.

An assumption made in the above formulation is that aircraft inventoried at origin or destination airfields do not consume any MOG capacity. This is not strictly valid since inventoried aircraft take up parking space. However, since MOG figures are based on a host of other factors beside parking spaces, it is probably more accurate to model the problem as such. As noted in the Assumptions section in Chapter II, if the USAF could provide separate data for "parking space MOG" and "ground services MOG", a more accurate modelling approach would be possible.

## C. SUMMARY

The mathematical expressions for the objective function and constraints are summarized below:

- **Objective Function**

*Minimize Z* =

$$\sum_{u}\sum_{a}\sum_{r\in R_a}\sum_{t\in T_{uar}} (LatePenUE_u * DaysLate_{uart}) * TonsUE_{uart}$$

$$+ \sum_{u}\sum_{a}\sum_{r\in R_a}\sum_{t\in T_{uar}} (LatePenPAX_u * DaysLate_{uart}) * TPAX_{uart}$$

$$+ \sum_{u}\sum_{i}\sum_{k} (NoGoPenUE_u * UENoGo_{uik}) + (NoGoPenPAX_u * PAXNoGo_{uik}).$$

- **Constraints**

$$\sum_{a\in A_{bulk}}\sum_{r\in R_{aik}}\sum_{t\in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq MoveUE_{uik} \quad \forall \quad u,i,k : MoveUE_{uik}>0$$

$$\sum_{a\in A_{out}}\sum_{r\in R_{aik}}\sum_{t\in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq ProOut_u * MoveUE_{uik}$$

$$\forall \quad u,i,k : MoveUE_{uik}>0$$

$$\sum_{a\in A_{ovr}}\sum_{r\in R_{aik}}\sum_{t\in T_{uar}} TonsUE_{uart} + UENoGo_{uik} \geq (ProOver_u + ProOut_u) * MoveUE_{uik}$$

$$\forall \quad u,i,k : MoveUE_{uik}>0$$

$$\sum_{a}\sum_{r\in R_{aik}}\sum_{t\in T_{uar}} TPAX_{uart} + PAXNoGo_{uik} \geq MovePAX_{uik} \quad \forall \quad u,i,k : MovePAX_{uik}>0$$

$$\sum_{u}\sum_{r\in DR_i} X_{uart} + H_{ait} = H_{ai(t-1)} + Allot_{ait} + \sum_{r\in R_a}\sum_{t'+RTime_{air}=t} Y_{art'} \quad \forall \quad a,i,t$$

$$\sum_{i} Allot_{ait} \leq Supply_{at} \qquad \forall \quad a,t : Supply_{at} > 0$$

$$\sum_{r \in RR_k} Y_{art} + HP_{akt} = HP_{ak(t-1)} + \sum_{u} \sum_{r \in R_a} \sum_{\substack{T' \in T_{uar} \\ t' + DTime_{abr} = t}} X_{uart'} \qquad \forall \quad a,k,t$$

$$TPAX_{uart} \leq MaxPAX_a * X_{uart} \qquad \forall \quad u,a,r,t : t \in T_{uar}$$

$$TonsUE_{uart} + (PAXWt * TPAX_{uart}) \leq MaxLoad_{ar} * X_{uart} \qquad \forall \quad u,a,r,t : t \in T_{uar}$$

$$(PAXSqFt_a * TPAX_{uart}) + (UESqFt_u * TonsUE_{uart}) \leq ACSqFt_a * LoadEff_a * X_{uart}$$
$$\forall \quad u,a,r,t : t \in T_{uar}$$

$$\sum_{u} \sum_{r \in R_a} \sum_{t \in T_{uar}} (FltTime_{ar} * X_{uart}) + \sum_{r \in R_a} \sum_{t} (FltTime_{ar} * Y_{art})$$
$$\leq \sum_{t : Supply_{at} > 0} URate_a * EffTime_t * Supply_{at} \qquad \forall \quad a$$

$$\sum_{u} \sum_{a} \sum_{r \in R_a} \sum_{\substack{t' \in T_{uar} \\ t' + DTime_{abr} = t}} (MOGReq_{ab} * DGTime_{abr} / 24) * X_{uart'}$$
$$+ \sum_{a} \sum_{r \in R_a} \sum_{t' + RTime_{abr} = t} (MOGReq_{ab} * RGTime_{abr} / 24) * Y_{art'}$$
$$\leq MOGEff * MOGCap_b \qquad \forall \quad b,t$$

$$X_{uart}, Y_{art}, Allot_{ait}, H_{ait}, HP_{akt}, TonsUE_{uart}, TPAX_{uart}, UENoGo_{uik}, PAXNoGo_{uik} \geq 0$$
$$\forall \quad u,a,r,t,i,k.$$

# IV. IMPLEMENTATION DETAILS

This chapter discusses the General Algebraic Modelling System (GAMS) implementation of the conceptual optimization model described in Chapter III and can be skipped without any loss in continuity. The materials of this chapter include key implementation features, and a mathematical formulation of the implemented model.

## A. ROUTE IMPLEMENTATION AND INDEX SUBSETS

The data structures used to implement air route structure and index subsets facilitate minimal external data processing.

### 1. Route Implementation

The air route structure of the optimization model is represented by five indices as opposed to a single index as described in the conceptual model. These five indices represent the origin, destination and three enroute airfields. The use of five airfield indices enable the model to distinguish the origin, enroute, and destination airfields and thus allows aircraft flight times and ground times to be calculated more easily. A graphical illustration of the air route structure is shown in Figure 1 (characters in the circular nodes are airfield GEOLOC codes).

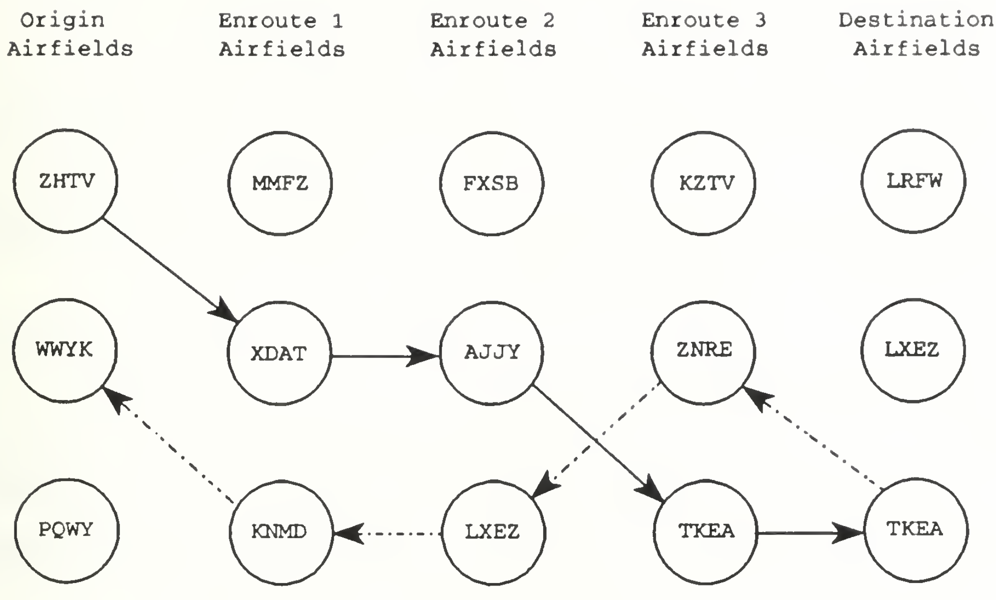


**Figure 1.** Air Route Structure

Although three indices are used to denote enroute stops, this does not imply that a delivery or recovery route must have three enroute stops. In fact, the model supports delivery/recovery routes with zero to three enroute stops. Routes with less than three enroute stops are implemented by replacing the non-existent enroute airfield names with the destination airfield name; e.g., the delivery route shown in Figure 1 has two enroute stops.

### 2. Index Subsets

Some of the index subsets of the conceptual model described in the previous chapter are not explicitly declared as a subset in the implemented model; i.e., they are not index subsets per se. Instead, these virtual index subsets are derived from the main index set through logical conditional checks performed by GAMS in model generation.

For example, the permitted delivery time window for each unit (a virtual subset) is generated by the model using relevant data such as the unit available load date, the required delivery date, and the time taken by an aircraft type to deliver the cargo. The generation of these induced virtual index subsets will become apparent in the objective function and constraint equations described below.

## B. MATHEMATICAL FORMULATION

The mathematical formulation of the optimization model as implemented in GAMS is given below. To facilitate a concise discussion, only index and data sets explicit in the objective function or constraints will be described. The interested reader can refer to the GAMS formulation in Appendix B for additional detail.

### 1. Indices

| | |
|---|---|
| u | unit; e.g., 82nd airborne |
| a | aircraft type; e.g., C5, C141 |
| ab | aircraft body type; e.g., wide-body (wb), narrow-body (nb) |
| ga | ground activity; e.g., load (onld), off-load (offld), enroute (enr) turnaround |
| t,tp | time period in days |
| c | cargo type; e.g., unit equipment (UE), troops (PAX) |
| cc | cargo class; e.g., bulk, over or out-sized cargo |
| af,afp | generic airfield |
| i | origin airfield; $I \subseteq AF$ |
| k | destination airfield in the theater; $K \subseteq AF$ |
| e1 | first enroute airfield; $E1 \subseteq AF$ |
| e2 | second enroute airfield; $E2 \subseteq AF$ |
| e3 | third enroute airfield; $E3 \subseteq AF$ |

Note: A compound index r will be used as a compact notation to represent the airfield indices (i,k,e1,e2,e3) in later discussions whenever appropriate.

### 2. Data

#### *a. Movement Requirement Data*

| | |
|---|---|
| MovePAX(u,i,k) | Troop movement requirement (in 100s) for unit *u* from origin *i* to destination *k* |
| MoveUE(u,i,k) | Equipment movement requirement (in 100 tons) for unit *u* from origin *i* to destination *k* |
| CargoP(u,cc) | Proportion of cargo classes (bulk, over, out) of unit *u* |
| ALD(u) | Available load date for unit *u* |
| RDD(u) | Required delivery date for unit *u* |

#### *b. Penalty Data*

| | |
|---|---|
| LatePen(u,c) | Lateness penalty for cargo type *c* of unit *u*. LatePen for troops is measured in terms of per 100 PAX per day and for equipment is in terms of per 100 ton per day. |
| NoGoPen(u,c) | Non-delivery penalty for cargo type *c* of unit *u*. NoGoPen for troops is measured in terms of per 100 PAX and for equipment is in terms of per 100 ton. |
| MaxLate | Maximum allowed lateness for delivery. This maximum lateness is necessary both for controlling the size of the time domain and to allow the LP to produce a feasible solution even when assets are inadequate. |

#### *c. Cargo Data*

| | |
|---|---|
| UESqFt(u) | Average cargo space (in 1000 sq. ft.) taken up by 100 tons of unit *u*'s equipment |
| PAXWt | Average weight (in 100 tons) of 100 troops inclusive of personal equipment |

#### *d. Aircraft Data*

| | |
|---|---|
| Supply(a,t) | Additional number of aircraft *a* made available on day t |
| ACCargo(a,cc) | Aircraft-cargo class matching table; a value of '1' indicates compatibility |
| MaxPAX(a) | Maximum troop carriage capacity (in 100s) of aircraft *a* |
| PAXSqFt(a) | Average cargo space (in 1000 sq. ft.) consumed by 100 soldiers for aircraft *a* |
| ACSqFt(a) | Cargo floor space (in 1000 sq. ft.) of aircraft *a* |
| LoadEff(a) | Cargo space loading efficiency for aircraft *a* |
| GTime(a,ga) | Ground time required to accomplish ground activity *ga* for aircraft *a* |
| URate(a) | Established utilization rate (in 100 flying hours per aircraft per day) for aircraft *a* |

#### *e. Airfield Data*

| | |
|---|---|
| MOGCap(af,"nb") | "Maximum On Ground" capacity for narrow-body aircraft at airfield *af* |
| MOGReq(af,a) | Normalized MOG requirement (to narrow-body aircraft) for aircraft *a* at airfield *af* |
| MOGEff | MOG efficiency factor; introduced as a discount factor as it is impossible to fully utilize the MOG capacity due to the stochastic nature of aircraft ground time |
| Dist(af,afp) | Distance (in nautical miles) between airfields *af* and *afp* |

#### *f. Aircraft Route Performance Data*

| | |
|---|---|
| MaxLoad(a,r) | Maximum payload (in 100 tons) for aircraft *a* flying on route *r* |

| | |
|---|---|
| CTtoE1(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on delivery route *r* to reach enroute *e1*. This cumulative time includes both flying time and ground time. |
| CTtoE2(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on delivery route *r* to reach enroute *e2* |
| CTtoE3(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on delivery route *r* to reach enroute *e3* |
| CTtoK(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on delivery route *r* to reach destination airfield *k* |
| RCTtoE3(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on recovery route *r* to reach enroute *e3* |
| RCTtoE2(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on recovery route *r* to reach enroute *e2* |
| RCTtoE1(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on recovery route *r* to reach enroute *e1* |
| RCTtoI(a,r) | Cumulative time (in hrs) taken by aircraft *a* flying on recovery route *r* to reach origin *i* |
| FltTime(a,r) | Total flight time (in 100 hrs) consumed by aircraft *a* flying on route *r*; excludes ground time |
| VRouteX(a,r) | A dynamic set with members indicating aircraft-delivery route compatibility. This set is used to control aircraft routing; e.g., military aircraft fly military routes and civilian aircraft fly civilian routes. |
| VRouteY(a,r) | A dynamic set with members indicating aircraft-recovery route compatibility |

### 3. Decision Variables

| | |
|---|---|
| X(u,a,r,t) | Number of aircraft *a* assigned to airlift unit *u*, via route *r* with mission start time *t*. An aircraft is permitted to carry only a single unit's cargo and troops as in a typical airlift mission |

| | |
|---|---|
| Y(a,r,t) | Number of aircraft *a* that recover from a destination airfield via route *r* with start time *t* |
| Allot(a,i,t) | Additional number of aircraft *a* available from day *t* that are allocated to origin *i* |
| H(a,i,t) | Number of aircraft *a* inventoried at origin *i* at time *t* |
| HP(a,k,t) | Number of aircraft *a* inventoried at destination *k* at time *t* |
| TonsUE(u,a,r,t) | Total tonnage (in 100 tons) of unit *u* equipment airlifted by aircraft *a*, via route *r* with mission start time *t* |
| TPAX(u,a,r,t) | Total number of unit *u* troops airlifted by aircraft *a* via route *r* with mission start time *t* |
| UENoGo(u,i,k) | Total tonnage (in 100 tons) of unit *u* equipment not airlifted from origin *i* to destination *k* in the prescribed time frame |
| PAXNoGo(u,i,k) | Number of unit *u* troops (in 100s) not airlifted from origin *i* to destination *k* in the prescribed time frame |

### 4. Dynamic Sets

Two dynamic sets, DSetX(u,a,r,t) and DSetY(a,r,t), are used repeatedly throughout the formulation of the objective and constraint equations to reduce the number of decision variables and thus the size of the LP.

The dynamic sets serve two purposes. First, they control the allowable combination of unit *u*, aircraft *a*, route *r* and mission start time *t* for airlift missions. Second, the dynamic sets eradicate certain combinations of decision variables that are known to have zero values at optimality; i.e., instead of keeping these decision variables in the LP model and letting the optimizer drive them to zero, these decision variables are removed from the model formulation.

### *a. DSetX(u,a,r,t)*

DSetX(u,a,r,t) is used to control the valid combination of unit *u*, aircraft *a*, route *r* and mission start time *t* for the following decision variables: X(u,a,r,t), TonsUE(u,a,r,t) and TPAX(u,a,r,t). For a combination to be valid, it must satisfy the following conditions:

- Mission start time *t* must satisfy the following two inequalities: $t \geq ALD(u)$ and $t \leq RDD(u) - [CTToK(a,r)/24] + MaxLate$; i.e., an unit can only be airlifted if it is ready to move and that the cargo will reach its destination before the required delivery date plus the maximum allowed lateness. Square brackets denote a "round operator"; e.g., [3.7] = 4 and [3.4] = 3

- There is movement requirement for unit *u* from origin airfield *i* to destination airfield *k*; i.e., MoveUE(u,i,k) > 0 or MovePAX(u,i,k) > 0

- Be a member of VRouteX(a,r); i.e., permitted aircraft-delivery route combination

- A particular aircraft-route combination is to be considered only if the permissible payload for the aircraft is at least 25 percent of the aircraft full load capability. This 25 percent factor is for cost efficiency and is also representative of real airlift operations.

- Supply of aircraft type up to time *t* is greater than zero

### *b. DSetY(a,r,t)*

DSetY(a,r,t) is used to control the valid combination of aircraft *a*, route *r* and start time *t* for the recovery decision variable Y(a,r,t). For a combination to be valid, it must satisfy the following conditions:

- Be a member of VRouteY(a,r); i.e., permitted aircraft-recovery route combination

- Supply of aircraft type up to time *t* is greater than zero

### 5. Objective Function

The model objective is to minimize the total weighted penalties (weighted by the movement priority of a unit) for late deliveries and undelivered cargo and troops. The objective function, z, is given by:

$$Minimize\ Z =$$

$$\sum_{u} \sum_{a} \sum_{r} \sum_{t \in DSetX(u,a,r,t)}$$

$$(LatePen(u,''UE'') * Max(0,(t + [CTtoK(a,r)/24] - RDD(u))) * TonsUE(u,a,r,t)$$
$$+ \ (LatePen(u,''PAX'') * Max(0,(t + [CTtoK(a,r)/24] - RDD(u))) * TPAX(u,a,r,t)$$

$$+ \sum_{u} \sum_{i} \sum_{k: MoveUE(u,i,k) > 0 \, or \, MovePAX(u,i,k) > 0}$$

$$(NoGoPen(u,''UE'') * UENoGo(u,i,k)) \ + \ (NoGoPen(u,''PAX'') * PAXNoGo(u,i,k)).$$

$$Note: \ \sum_{r} \equiv \sum_{i} \sum_{k} \sum_{e1} \sum_{e2} \sum_{e3}$$

The number of days late in delivery for a particular unit *u*, aircraft *a*, route *r* and mission start time *t* combination is given by the GAMS function *Max(a,b)* where a and b are numerical values or arithmetic expressions. For cargo and troops delivered to the theater on or before the required delivery date no penalty is incurred. For cargo and troops delivered late, the number of days late in delivery is equal to the mission start time plus time taken by the aircraft to deliver the cargo and troops minus the required delivery date.

### 6. Constraints

The objective function is subject to the following constraints.

### a. *Demand Satisfaction Constraints*

The constraints for satisfying demand are the requirements for troops and the different classes of cargo (bulk, over and out-sized). There are four different kinds of demand satisfaction constraints (one for troops and three for cargo). Three separate constraints are required for cargo due to the need to ensure aircraft-cargo compatibility. The demand satisfaction constraints follow:

*(1) Demand Satisfaction Constraints for All Classes of Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment delivered to the theater by all aircraft types (over all permissible route and mission start time combination) plus total tonnage not delivered (UENoGo) must be greater than or equal to the movement requirement for equipment:

$$\sum_{a:ACCargo(a,''bulk'')>0} \sum_{e1} \sum_{e2} \sum_{e3} \sum_{t \in DSetX(u,a,r,t)} TonsUE(u,a,r,t) + UENoGo(u,i,k)$$

$$\geq MoveUE(u,i,k) \qquad \forall \quad u,i,k : MoveUE(u,i,k) > 0.$$

*(2) Demand Satisfaction Constraints for Out-Sized Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment carried by out-sized cargo capable aircraft plus the total tonnage not delivered must be greater than or equal to the movement requirement for out-sized cargo (given by proportion of out-sized cargo multiplied by movement requirement for equipment):

$$\sum_{a:ACCargo(a,''out'')>0} \sum_{e1} \sum_{e2} \sum_{e3} \sum_{t \in DSetX(u,a,r,t)} TonsUE(u,a,r,t) + UENoGo(u,i,k)$$

$$\geq CargoP(u,''out'') * MoveUE(u,i,k) \qquad \forall \quad u,i,k : MoveUE(u,i,k) > 0.$$

*(3) Demand Satisfaction Constraints for Over-Sized Cargo.* For each unit and associated origin-destination pair, the total tonnage of unit equipment carried by over-sized cargo capable aircraft plus the total tonnage not delivered must be greater than or equal to the movement requirement for over and out-sized cargo:

$$\sum_{a:ACCargo(a,''over'')>0} \sum_{e1} \sum_{e2} \sum_{e3} \sum_{t \in DSetX(u,a,r,t)} TonsUE(u,a,r,t) + UENoGo(u,i,k)$$

$$\geq (CargoP(u,''over'') + CargoP(u,''out'')) * MoveUE(u,i,k)$$

$$\forall \quad u,i,k : MoveUE(u,i,k) > 0.$$

The right-hand-side of the constraint is valid because out-sized cargo capable carriers are also over-sized cargo capable.

*(4) Demand Satisfaction Constraints for Troops.* For each unit and associated origin-destination pair, the total number of troops airlifted to the theater plus those not airlifted must be greater than or equal to the movement requirement for troops:

$$\sum_{a} \sum_{e1} \sum_{e2} \sum_{e3} \sum_{t \in DSetX(u,a,r,t)} TPAX(u,a,r,t) + PAXNoGo(u,i,k) \geq MovePAX(u,i,k)$$

$$\forall \quad u,i,k : MovePAX(u,i,k) > 0.$$

*b. Aircraft Balance Constraints*

The number of aircraft *a* assigned for airlift missions (or to be recovered) must be no more than the number of aircraft *a* available for use. The three different kinds of aircraft balance constraints are:

*(1) Aircraft Balance Constraint at Origin Airfield.* For each aircraft *a*, origin *i* and time period *t* combination, the total number of aircraft assigned for airlift

missions, plus those inventoried must be equal to the total number of aircraft available from the previous period plus new supply of aircraft allocated to the origin and returns from previous missions:

$$\sum_{u}\sum_{k}\sum_{e1}\sum_{e2}\sum_{e3\in DSetX(u,a,r,t)} X(u,a,r,t) + H(a,i,t)$$

$$= H(a,i,t-1) + Allot(a,i,t) + \sum_{k}\sum_{e1}\sum_{e2}\sum_{e3}\sum_{\substack{tp\in DSetY(a,r,tp)\\ tp+[RCTtoI(a,r)/24]=t}} Y(a,r,tp) \quad \forall \quad a,i,t.$$

*Note*: *$H(a,i,t-1)$ is only defined for $t$ greater than* 1.

*(2) Balance Constraint for Aircraft Allocation.* The total number of aircraft $a$ allocated to the different origin airfields in each time period $t$ must be no more than the new supply of aircraft $a$:

$$\sum_{i} Allot(a,i,t) \le Supply(a,t) \qquad \forall \quad a,t : Supply(a,t)>0.$$

*(3) Aircraft Balance Constraint at Destination Airfield.* For each aircraft $a$, destination $k$ and time period $t$ combination, the total number of aircraft $a$ recovering from the destination airfield this period plus those inventoried must be equal to those waiting to return (inventory from last period) plus new arrivals at the destination:

$$\sum_{i}\sum_{e1}\sum_{e2}\sum_{e3\in DSetY(a,r,t)} Y(a,r,t) + HP(a,k,t)$$

$$= HP(a,k,t-1) + \sum_{u}\sum_{i}\sum_{e1}\sum_{e2}\sum_{e3}\sum_{\substack{tp\in DSetX(u,a,r,tp)\\ tp+[CTtoK(a,r)/24]=t}} X(u,a,r,tp) \quad \forall \quad a,k,t.$$

*Note*: *$HP(a,k,t-1)$ is only defined for $t$ greater than* 1.

### c. *Aircraft Physical Limitation Constraints*

The aircraft physical limitation constraints modelled are the troop carriage capacity, maximum payload and cargo floor space constraints.

*(1) Troop Carriage Capacity Constraints.* The total number of troops airlifted for each unit $u$, aircraft $a$, route $r$, and mission start time $t$ combination must not be greater than the troop carriage capacity of aircraft $a$ multiplied by the number of aircraft $a$ assigned:

$$TPAX(u,a,r,t) \leq MaxPAX(a) * X(u,a,r,t) \qquad \forall \quad u,a,r,t \in DSetX(u,a,r,t).$$

*(2) Maximum Payload Constraints.* The total payload (equipment and men) airlifted for each unit $u$, aircraft $a$, route $r$, and mission start time $t$ combination must not be greater than the maximum payload for aircraft $a$ flying route $r$, multiplied by the number of aircraft $a$ assigned:

$$TonsUE(u,a,r,t) + (PAXWt * TPAX(u,a,r,t)) \leq MaxLoad(a,r) * X(u,a,r,t)$$
$$\forall \quad u,a,r,t \in DSetX(u,a,r,t).$$

*(3) Cargo Floor Space Constraints.* The total floor space taken up by troops and equipment for each unit $u$, aircraft $a$, route $r$, and mission start time $t$ combination must not be greater than the aircraft cargo floor space multiplied by the loading efficiency factor and number of aircraft $a$ assigned:

$$(PAXSqFt(a) * TPAX(u,a,r,t)) + (UESqFt(u) * TonsUE(u,a,r,t))$$
$$\leq ACSqFt(a) * LoadEff(a) * X(u,a,r,t)$$
$$\forall \quad u,a,r,t \in DSetX(u,a,r,t), \quad ACSqFt(a) > 0.$$

#### d. *Aircraft Utilization Rate Constraints*

These constraints ensure that the average flying hours consumed per aircraft per day is less than AMC's established utilization rate for each aircraft type. Aircraft utilization rate constraints are modelled by comparing the actual flying hours consumed by an aircraft fleet in a deployment with the maximum achievable flying hours based on the utilization rate. The total flying hours consumed by an aircraft fleet in a deployment is equal to the total flying hours consumed on both delivery and recovery routes. The maximum achievable flying hours for each aircraft is given by the utilization rate multiplied by the number of productive time periods of that aircraft (CARD(t) represent the time horizon in the equation).

$$\sum_{u}\sum_{r}\sum_{t \in DSetX(u,a,r,t)} FltTime(a,r) * X(u,a,r,t) + \sum_{r}\sum_{t \in DSetY(a,r,t)} FltTime(a,r) * Y(a,r,t)$$

$$\leq \sum_{t: Supply(a,t) > 0} URate(a) * (CARD(t) + 1 - t) * Supply(a,t) \quad \forall \quad a.$$

#### e. *Aircraft Handling Capacity of Airfield (MOG Constraint)*

These constraints model the throughput or handling capacity of each airfield. They ensure that the LP does not route more aircraft through an airfield than it can handle each day.

The aircraft handling capacity constraints are modelled by computing the total MOG consumed (normalized to that of a narrow-body aircraft for comparison) in each period by each individual aircraft using the airfield. An airfield can serve as an origin, enroute, or a destination airfield; thus the total MOG consumed at a particular airfield on each day is the sum of the individual consumptions when serving in these

different capacities. The total MOG consumed must be less than the normalized MOG capacity of the airfield discounted by the MOG efficiency factor (it is impossible to fully utilize the MOG capacity due to deviations from scheduled ground times).

The airfield capacity that an aircraft consumes is equal to its MOG requirement multiplied by the ratio of time spent (in hours) under service to number of hours in a time period (in this case, 24 hours). MOG requirement are normalized to that of a narrow-body aircraft. The amount of time an aircraft spends at origin, enroute and destination airfields are the loading time (onload), enroute refuelling time (enr) and off-load time (offld) respectively. In the formulation of the constraints, MOG consumption at the origin and destination airfields are associated with the X(u,a,r,t) variables only whereas, the MOG consumption at enroute airfields are associated with both the X(u,a,r,t) and Y(u,a,r,t) variables.

As the model supports air routes with zero to three enroute stops, it is also necessary to ensure that there is no double counting of MOG consumption (destination airfield names are used to replace non-existent enroute airfield names). Potential double counting of MOG consumption is prevented through conditional checks performed by the constraint equations. The constraint equation follows:

$$\sum_{u}\sum_{a}\sum_{k}\sum_{e1}\sum_{e2}\sum_{e3 \in DSetX(u,a,af,k,e1,e2,e3,t)} (MOGReq(af,a) * GTime(a,''onld'')/24) * X(u,a,af,k,e1,e2,e3,t)$$

$$+ \sum_{u}\sum_{a}\sum_{i}\sum_{k}\sum_{e2}\sum_{e3}\sum_{\substack{tp \in DSetX(u,a,i,k,af,e2,e3,tp) \\ tp + [CTtoE1(a,r)/24] = t \\ Dist(i,af) \neq 0 \\ CTtoE1(a,r) \neq CTtoK(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * X(u,a,i,k,af,e2,e3,tp)$$

$$+ \sum_{a}\sum_{i}\sum_{k}\sum_{e2}\sum_{e3}\sum_{\substack{tp \in DSetY(a,i,k,af,e2,e3,tp) \\ tp + [RCTtoE1(a,r)/24] = t \\ Dist(af,e2) \neq 0 \\ RCTtoE1(a,r) \neq RCTtoI(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * Y(a,i,k,af,e2,e3,tp)$$

$$+ \sum_{u}\sum_{a}\sum_{i}\sum_{k}\sum_{e1}\sum_{e3}\sum_{\substack{tp \in DSetX(u,a,i,k,e1,af,e3,tp) \\ tp + [CTtoE2(a,r)/24] = t \\ Dist(e1,af) \neq 0 \\ CTtoE2(a,r) \neq CTtoK(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * X(u,a,i,k,e1,af,e3,tp)$$

$$+ \sum_{a}\sum_{i}\sum_{k}\sum_{e1}\sum_{e3}\sum_{\substack{tp \in DSetY(a,i,k,e1,af,e3,tp) \\ tp + [RCTtoE2(a,r)/24] = t \\ Dist(af,e3) \neq 0 \\ RCTtoE2(a,r) \neq RCTtoI(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * Y(a,i,k,e1,af,e3,tp)$$

$$+ \sum_{u}\sum_{a}\sum_{i}\sum_{k}\sum_{e1}\sum_{e2}\sum_{\substack{tp \in DSetX(u,a,i,k,e1,e2,af,tp) \\ tp + [CTtoE3(a,r)/24] = t \\ Dist(e2,af) \neq 0 \\ CTtoE3(a,r) \neq CTtoK(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * X(u,a,i,k,e1,e2,af,tp)$$

$$+ \sum_{a}\sum_{i}\sum_{k}\sum_{e1}\sum_{e2}\sum_{\substack{tp \in DSetY(a,i,k,e1,e2,af,tp) \\ tp + [RCTtoE3(a,r)/24] = t \\ Dist(af,k) \neq 0 \\ RCTtoE3(a,r) \neq RCTtoI(a,r)}} (MOGReq(af,a) * GTime(a,''enr'')/24) * Y(a,i,k,e1,e2,af,tp)$$

$$+ \sum_{u}\sum_{a}\sum_{i}\sum_{e1}\sum_{e2}\sum_{e3}\sum_{\substack{tp \in DSetX(u,a,i,af,e1,e2,e3,tp) \\ tp + [CTtoK(a,r)/24] = t}} (MOGReq(af,a) * GTime(a,''offld'')/24) * X(u,a,i,af,e1,e2,e3,tp)$$

$$\leq \quad MOGEff * MOGCap(af,''nb'') \qquad \forall \quad af,t.$$

The conditional checks differ due to the multiple roles (origin, enroute and destination) that an airfield may serve. When the airfield is serving as an origin, the conditional check will ensure that only permissible airlift missions are allowed; i.e., valid combination of unit $u$, aircraft $a$, route $r$, and mission start time $t$.

When the airfield is serving as an enroute, four conditional checks are required. The first conditional check ensures a valid combination of indices; i.e., permissible unit $u$, aircraft $a$, mission start time $t$ combination. The second conditional check ensures that the time of arrival at the airfield is the time period of concern. The third conditional check ensures that the aircraft come from a different airfield and serves the purpose of preventing double counting. The fourth conditional check ensures that the time taken to reach the airfield of concern is not equal to the time required to reach the destination (or origin) airfield. This last check also ensures that proper aircraft ground time is used in the MOG computation. For example, if the time taken to reach enroute $e3$ and destination $k$ are the same, this implies that the aircraft has reached its destination and no enroute airfield capacity should be consumed. The corresponding aircraft off-load MOG consumption is computed when the airfield is considered as a destination node.

When serving as a destination airfield, two conditional checks are required. The first conditional check ensures a valid combination of indices. The second conditional check ensures that the time of arrival at the airfield is the time period of concern.

# V. PERFORMANCE, ANALYTIC INSIGHTS AND LIMITATIONS

## A. PERFORMANCE

The performance of the optimization model on the IBM RS6000 model 590 Unix workstation is relatively fast. For a sample problem with 20 units, 7 aircraft types, 17 airfields and 30 time periods, GAMS/XA and GAMS/OSL generated and solved the LP problem in about 90 seconds. There were 8273 permissible decision variables and 6349 constraint equations after all the problem reduction using dynamic sets were performed. The optimization model takes about 10 times longer when the same problem is solved on a personal computer (486/33 AT machine with 32MB of RAM). The total generation and solve times on the personal computer is about 15 minutes.

The manner in which the optimization model is implemented reduces the amount of external data processing and data entry time (as most data can be entered in the format in which they are made available). For example, with readily available airfields' geographical location and aircraft's cruise speed data, the model computes the cumulative time a particular aircraft takes to reach a designated airfield along a route. The data entry time for the above sample problem is about one and a half hours.

Thus, it can be seen that the overall response time of the model (under 2 hours) is relatively fast; this is a strength of the model.

## B. ANALYTIC INSIGHTS

Broad insights into the strategic airlift system can be gained from the optimization model. For any particular set of input data, the insights gained include answers to the following mobility questions:

- Adequacy of Assets: Indicate whether aircraft and airfield assets are adequate for a deployment scenario.

- Impact of Any Shortfall in Airlift Capability: Allow the analyst to assess the impact by reporting the number of troops and tons of equipment of each unit that are airlifted late or could not be airlifted.

- System "bottle-necks": Indicate which part (aircraft or airfields) of the airlift system is restricting the flow of troops and equipment. These reports can also give ideas on how to improve the airlift system output. For example, increasing the material handling equipment in those airfields that support a large number of aircraft (high MOG consumption) can increase aircraft handling capacity. An analyst can also gauge the optimal number of CRAF aircraft to mobilize. For example, if the system is airfield constrained then mobilizing additional CRAF assets may not help the system; on the contrary, it may increase congestion and cost.

- Balance aircraft and airfields assets: This factor is important as there are limited military budgets and the USAF has to make a trade-off between buying aircraft and keeping airfields open. Ideally, the combination of assets should be such that aircraft utilization rates and airfields MOG consumption for most deployment scenarios are close to their published capacities. This is to ensure a good aircraft to airfield ratio.

- Fleet Mix Studies: By running different deployment scenarios, an analyst is able to assess which assets-mix option is the best overall option for supporting the different regional contingency plans.

## C. MODEL LIMITATIONS

Two limitations of the optimization model are the inability to handle local traffic congestion and low fidelity. The true impact of these limitations are not quantifiable at the moment, and further validation and research are needed before it can be ascertained. These two limitations are caused by a mismatch between the time resolution (in days) and aircraft flying time and ground time (in hours). A more refined time resolution was not used in this research as initial investigation indicated that the problem size is large and requires data aggregation. A more refined time resolution though desired (more time periods for the same number of days) may increase the LP size beyond GAMS or the solvers' capability. This time resolution issue, however, warrants further investigation.

### 1. Local Traffic Congestion

Although the aircraft handling capacity of each airfield is observed by the model, airlift missions may still be routed in a manner that causes local congestion. For example, all aircraft routed through an airfield on a particular day could arrive within a small time window instead of being spread over the whole day. In reality, this would cause local congestion, even though the model's representation of aircraft handling capacity is observed.

### 2. Low Fidelity

The arrivals of aircraft at the origin and destination airfields are rounded-off to the nearest day (resolution of the time period). This round-off affects the fidelity and accuracy of the model. For example, rounding-off may increase the MOG consumption

of an airfield on one day and decrease the MOG consumption of the same airfield on the next day. Round-off results in lumpy flows through airfields, and hence, errs on the side of pessimism when MOG represents a binding constraint on the system flow. This is to be contrasted with the more optimistic smoothing fractional flow approach utilized by RAND in CONOP [Ref. 4].

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

The USAF strategic airlift system has been successfully modelled (although not in its entirety as use of tanker aircraft are not incorporated) as a multi-commodity, multi-period network flow model with a large number of side constraints.

Broad insights (some of which are currently not available from existing models such as Thruput or MOM) into the strategic airlift system can be gained by using the model. Some of the insights that can be gained include identification of system "bottle-necks" and the impact of any shortfall in airlift capability.

In addition to providing insights into the airlift system, the model also has relatively fast turnaround time. This virtue makes the model a useful tool in situations (e.g., initial planning phase of a major regional conflict development) where time is of the essence and where quick answers are desired. Its ability to furnish quick answers without tying down a massive amount of manpower or computer resources is important in such time critical circumstances.

## B. RECOMMENDATIONS

The following are some recommendations for model enhancement.

### 1. Incorporate Use of Tanker Aircraft

One enhancement to the model is to incorporate the use of tanker aircraft in a deployment scenario. Such an enhancement would allow the airlift system to be examined from a much wider perspective. A possible way to incorporate the use of tanker aircraft is the "airbase in the sky" concept employed by RAND's CONOP optimization model. This concept basically treats the aerial refuelling areas as enroute airfields and can be implemented in the existing model without major changes to GAMS code. A more realistic representation of aerial refueling would also accounts for "diverts", i.e., planned aerial refueling which are not executed for unplanned reasons. Incorporating this enhancement would require major research and development.

### 2. Increase MOG Fidelity

For a more accurate modelling approach, it is essential that "ground services MOG" be distinguished from "parking space MOG". This distinction is necessary as aircraft inventoried at the origin and destination airfields require only "parking space MOG" and not "ground services MOG" once they have loaded or unloaded their cargo. This point has been covered in the Assumptions section in Chapter II. If data were available, it would be easy to formulate MOG constraints for each of several ground services.

### 3. Investigate the Feasibility of Improving Time Resolution

Another possible enhancement to the model is to improve the resolution of the time period (e.g., time could be discretized into 12 hour or smaller blocks instead of

days). Such an improvement if feasible would certainly improve the fidelity of the model and alleviate the two limitations of the models cited in Chapter V. However, improving the resolution of the time period does has a high price in terms of increasing the size of the LP. It is therefore prudent to assess the relative merits before embarking on such a move.

### 4. Validate MOG Efficiency Factor

The MOG efficiency factor is introduced as a discount factor to offset the effect of random aircraft ground times (which implies that an airfield cannot be planned to be fully utilized). The appropriate efficiency factor however, is presently unknown and needs to be investigated. One possible approach is to employ a simulation model to help obtain a realistic efficiency factor.

### 5. Stochastic Modelling

Aircraft reliability and ground times at on-load, off-load, and enroute airfields are inherently random aspects of a strategic airlift system. These stochastic factors can significantly affect the performance of an airlift system, particularly when infrastructure (e.g., airfield capacity) represents a binding constraint. One possible enhancement to the deterministic model is to apply stochastic optimization to develop a strategic airlift model in which aircraft reliability and ground times are modeled as random variables with known distribution.

# APPENDIX A. LISTING OF DATA SOURCES

This appendix is a listing of the data sources. The layout is in the order of the entity name (as in the GAMS formulation) followed by a short description and the source from which the data originate.

## A. MOVEMENT REQUIREMENT DATA

| Name | Description | Source |
|---|---|---|
| MoveUE(u,i,k) | Movement requirement for equipment | scenario |
| CargoP(u,cc) | Proportion of cargo classes (bulk, over, out) | scenario |
| MovePAX(u,i,k) | Movement requirement for troops | scenario |
| ALD(u) | Available load date | scenario |
| RDD(u) | Required delivery date | scenario |

## B. PENALTY DATA

| Name | Description | Source |
|---|---|---|
| LatePen(u,c) | Lateness penalty | analyst's input |
| NoGoPen(u,c) | Non-delivery penalty | analyst's input |
| MaxLate | Maximum allowed lateness for delivery | analyst's input |

## C. CARGO DATA

| Name | Description | Source |
|---|---|---|
| UESqFt(u) | Cargo space taken up by equipment | scenario |
| PAXWt | Average troop weight | AMC Load Planning Guide |

## D. AIRCRAFT DATA

| Name | Description | Source |
|---|---|---|
| Supply(a,t) | New aircraft made available | scenario |
| ACSize(a,ab) | Aircraft body type | AMC |
| ACCargo(a,cc) | Aircraft-cargo compatibility | AMC |
| MaxPAX(a) | Aircraft troop carriage capacity | AFR 76-2, AMCP 55-41 |
| PAXSqft(a) | Cargo space consumed by a soldier | aircraft-9, 55-41 |
| ACSqFt(a) | Cargo space available | AMC Load Planning Guide |

D. AIRCRAFT DATA (continued)

| Name | Description | Source |
|---|---|---|
| LoadEff(a) | Cargo space loading efficiency | analyst's input |
| Spd(a) | Aircraft block speed | AMC |
| GTime(a,ga) | Aircraft ground time | AMC |
| URate(a) | Established utilization rate | AMC |
| ACRange(a,rangeband) | Aircraft range points | aircraft-9, 55-41 |
| ACLoad(a,rangeband) | Aircraft load at range point | aircraft-9, 55-41 |

E. AIRFIELD DATA

| Name | Description | Source |
|---|---|---|
| Crd(af,coords) | Decimal airfield coordinates | JFAST GEOFILE database |
| MOGCap(af,ab) | MOG capacity by aircraft type | AMC |
| MOGEff | MOG efficiency factor | analyst's input |

F. AIRCRAFT-ROUTE DATA (Dynamic Sets)

| Name | Description | Source |
|---|---|---|
| VRouteX(a,i,k,e1,e2,e3) | Aircraft-delivery route compatibility dynamic set | analyst's input |
| VRouteY(a,i,k,e1,e2,e3) | Aircraft-recovery route compatibility dynamic set | analyst's input |

The above are the original data that are required by the program. All other data are computed by the GAMS model itself.

# APPENDIX B. GAMS FORMULATION LISTING

```
GAMS 2.25.064  AIX RS/6000P
09/07/94 09:58:22
Strategic Airlift Asset Optimization Model  Spring 1994

*  Thesis by: Cpt Lim, Teo-Weng
*  Advisors:  Professor Richard E. Rosenthal
*             Dr. David P. Morton
*             Professor Gerald G. Brown
*  Naval PostGraduate School
*
*---------------  GAMS AND DOLLAR CONTROL OPTIONS  ---------------

OPTIONS
   LIMCOL =  0, LIMROW  = 0    , SOLPRINT = OFF, DECIMALS = 2
   RESLIM = 18000, ITERLIM = 400000, OPTCR    = 0.1 , SEED = 3141;

*++++++++++++++++++++  INDICES DECLARATION  ++++++++++++++++++++

SETS

  U   units
INCLUDE    /home/limt/unitname.dat
/
UnitA   USMC 3 MAB
UnitB   USMC 1 MAF
UnitC   USMC 2 MAB
UnitD   USA 4 Light Inf
UnitE   USA 2 Mech
UnitF   USA 25 AAD
UnitG   24 A10s
UnitH   24 F16s and 24 F15s
UnitI   24 A10s
UnitJ   24 F16s and 24 F15s
UnitK   24 A10s
UnitL   24 F16s
UnitM   24 F15s
UnitN   24 A10s
UnitO   24 F16s
UnitP   24 F15s
UnitQ   24 F16s and 24 F15s
UnitR   24 F16s and 24 F15s
UnitS   24 F16s and 24 F15s
UnitT   24 F16s and 24 F15s
/

  A   aircraft
INCLUDE    /home/limt/acname.dat
/
C5
C17
C141
C130
747P
```

```
747C
DC10
/

   CRAF(A)   civilian aircraft
INCLUDE    /home/limt/craf.dat
/
747P
747C
DC10
/

   MILAC(A)   military aircraft
INCLUDE    /home/limt/milac.dat
/
C5
C17
C141
C130
/

   AB   aircraft body type
*  Aircraft are classified as WB (widebody), NB (narrow body),
*  GM (ground manuverable), or TT (tactical).
     / WB, NB, GM, TT /

   GA   ground activities
*  The different types of ground activities an aircraft goes
*  through are on-load (ONLD), enroute turnaround (ENR) and
*  off-load (OFFLD).
      / ONLD, ENR, OFFLD /

   T   time periods in days
INCLUDE    /home/limt/periods.dat
*  Time period should cover up till the last RDD plus
*  the maximum allowed lateness
/
DAY1 * DAY30
/

ALIAS(T,TP);

SETS

   C   cargo type   / UE, PAX /
* UE stands for unit equipment and PAX for troops

   CC   cargo class   / BULK, OVER, OUT /

   AF   airfields in general
INCLUDE    /home/limt/afname.dat
/
QFQE   Mildenhall
TMKH   Pope AFB
TYFR   Ramstein AB
XDAT   Travis AFB
FFTJ   Dhahran
UGZX   Riyadh
PKVV   Masirah
KNMD   Hickam
```

```
FXSB   Elmendorf AFB
WWYK   Tinker AFB
NNGX   Boston Logan
UTKY   San Francisco Int
FJXT   Dover AFB
ZNRE   Yokota
HTDS   London Gatwick
FGDC   Diego Garcia NAF
XBGX   Torrejon
/
  I(AF)   origin airfields
INCLUDE    /home/limt/orgname.dat
/
QFQE   Mildenhall
TMKH   Pope AFB
TYFR   Ramstein AB
XDAT   Travis AFB
/
  K(AF)   destination airfields in theater
INCLUDE    /home/limt/destname.dat
/
FFTJ   Dhahran
UGZX   Riyadh
PKVV   Masirah
/
  E1(AF)   first set of enroute airfields
INCLUDE    /home/limt/e1name.dat
/
QFQE   Mildenhall
TMKH   Pope AFB
TYFR   Ramstein AB
XDAT   Travis AFB
KNMD   Hickam
FXSB   Elmendorf AFB
WWYK   Tinker AFB
NNGX   Boston Logan
UTKY   San Francisco Int
FJXT   Dover AFB
/
  E2(AF)   second set of enroute airfields
INCLUDE    /home/limt/e2name.dat
/
QFQE   Mildenhall
TYFR   Ramstein AB
FFTJ   Dhahran
UGZX   Riyadh
PKVV   Masirah
KNMD   Hickam
ZNRE   Yokota
HTDS   London Gatwick
/
  E3(AF)   third set of enroute airfields
INCLUDE    /home/limt/e3name.dat
/
TYFR   Ramstein AB
```

```
FFTJ   Dhahran
UGZX   Riyadh
PKVV   Misarah
FGDC   Diego Garcia NAF
XBGX   Torrejon
/
;

SET VROUTEX(A,I,K,E1,E2,E3)  indicate aircraft-delivery route
*                            compatibility ;
*  Used to control aircraft-route matching; i.e., allow military
*  aircraft to fly on military routes and civilian aircraft to fly
*  on civilian routes.  Members of SET indicate compatibility.
INCLUDE    /home/limt/vroutex.set
*  Member indicates aircraft-route compatibility
*  Substitute destination name for E1, E2, E3 when such enroute
*  airfields are not needed.
VRouteX(MILAC,"TMKH","FFTJ","WWYK","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","UGZX","WWYK","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","FFTJ","TYFR","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","UGZX","TYFR","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","FFTJ","QFQE","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","UGZX","QFQE","UGZX","UGZX") = yes;
VRouteX(CRAF,"TMKH","FFTJ","TMKH","TYFR","FFTJ") = yes;
VRouteX(CRAF,"TMKH","UGZX","TMKH","TYFR","UGZX") = yes;
VRouteX(CRAF,"TMKH","PKVV","TMKH","TYFR","PKVV") = yes;
VRouteX(CRAF,"TMKH","FFTJ","TMKH","HTDS","FFTJ") = yes;
VRouteX(CRAF,"TMKH","UGZX","TMKH","HTDS","UGZX") = yes;
VRouteX(CRAF,"TMKH","PKVV","TMKH","HTDS","PKVV") = yes;
VRouteX(MILAC,"XDAT","FFTJ","WWYK","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","FFTJ","WWYK","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"XDAT","UGZX","WWYK","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","UGZX","WWYK","UGZX","UGZX") = yes;
VRouteX(MILAC,"XDAT","FFTJ","TYFR","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","FFTJ","TYFR","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"XDAT","UGZX","TYFR","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","UGZX","TYFR","UGZX","UGZX") = yes;
VRouteX(MILAC,"XDAT","FFTJ","QFQE","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"TMKH","FFTJ","QFQE","FFTJ","FFTJ") = yes;
VRouteX(MILAC,"XDAT","UGZX","QFQE","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","UGZX","QFQE","UGZX","UGZX") = yes;
VRouteX(CRAF,"XDAT","FFTJ","NNGX","TYFR","FFTJ") = yes;
VRouteX(CRAF,"XDAT","UGZX","NNGX","TYFR","UGZX") = yes;
VRouteX(CRAF,"XDAT","PKVV","NNGX","TYFR","PKVV") = yes;
VRouteX(CRAF,"XDAT","FFTJ","NNGX","HTDS","FFTJ") = yes;
VRouteX(CRAF,"XDAT","UGZX","NNGX","HTDS","UGZX") = yes;
VRouteX(CRAF,"XDAT","PKVV","NNGX","HTDS","PKVV") = yes;
VRouteX(A,"TYFR","FFTJ","TYFR","TYFR","FFTJ") = yes;
VRouteX(A,"TYFR","UGZX","TYFR","TYFR","UGZX") = yes;
VRouteX(A,"TYFR","PKVV","TYFR","TYFR","PKVV") = yes;
VRouteX(A,"QFQE","FFTJ","TYFR","FFTJ","FFTJ") = yes;
VRouteX(A,"QFQE","UGZX","TYFR","UGZX","UGZX") = yes;
VRouteX(A,"QFQE","PKVV","TYFR","PKVV","PKVV") = yes;
VRouteX(CRAF,"XDAT",K,"FXSB","ZNRE","FGDC") = yes;
VRouteX(CRAF,"XDAT",K,"XDAT","ZNRE","FGDC") = yes;
VRouteX(MILAC,"TMKH","PKVV","WWYK","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","PKVV","QFQE","UGZX","UGZX") = yes;
VRouteX(MILAC,"TMKH","PKVV","TYFR","UGZX","UGZX") = yes

SET VROUTEY(A,I,K,E1,E2,E3)  indicate aircraft-recovery route
```

```
     *                             compatibility ;
INCLUDE    /home/limt/vroutey.set
     *  Member indicates aircraft-route compatibility
     *  Substitute destination name for E1, E2, E3 when such enroute
     *  airfields are not needed
     VRouteY(MILAC,"TMKH","FFTJ","WWYK","FFTJ","FFTJ") = yes;
     VRouteY(MILAC,"TMKH","UGZX","WWYK","UGZX","UGZX") = yes;
     VRouteY(MILAC,"TMKH","FFTJ","TYFR","FFTJ","FFTJ") = yes;
     VRouteY(MILAC,"TMKH","UGZX","TYFR","UGZX","UGZX") = yes;
     VRouteY(MILAC,"TMKH","FFTJ","QFQE","FFTJ","FFTJ") = yes;
     VRouteY(MILAC,"TMKH","UGZX","QFQE","UGZX","UGZX") = yes;
     VRouteY(CRAF,"TMKH","FFTJ","NNGX","FFTJ","FFTJ") = yes;
     VRouteY(CRAF,"TMKH","UGZX","NNGX","UGZX","UGZX") = yes;
     VRouteY(CRAF,"TMKH","FFTJ","WWYK","FFTJ","FFTJ") = yes;
     VRouteY(CRAF,"TMKH","UGZX","WWYK","UGZX","UGZX") = yes;
     VRouteY(CRAF,"TMKH","FFTJ","TYFR","FFTJ","FFTJ") = yes;
     VRouteY(CRAF,"TMKH","UGZX","TYFR","UGZX","UGZX") = yes;
     VRouteY(CRAF,"TMKH","FFTJ","QFQE","FFTJ","FFTJ") = yes;
     VRouteY(CRAF,"TMKH","UGZX","QFQE","UGZX","UGZX") = yes;
     VRouteY(CRAF,"XDAT",K,"FXSB","ZNRE","FGDC") = yes;
     VRouteY(CRAF,"XDAT",K,"KNMD","ZNRE","FGDC") = yes;
     VRouteY(CRAF,"XDAT",K,"UTKY","ZNRE","FGDC") = yes;
     VRouteY(MILAC,"TMKH","PKVV","WWYK","UGZX","PKVV") = yes;
     VRouteY(MILAC,"TMKH","PKVV","QFQE","UGZX","PKVV") = yes;
     VRouteY(MILAC,"TMKH","PKVV","TYFR","UGZX","PKVV") = yes

     SET COORDS   coordinates  / LAT, LON /;

     *+++++++++++++++++  MOVEMENT REQUIREMENT DATA  +++++++++++++++++++

     PARAMETER MOVEUE(U,I,K)   units' equipment movement requirements
INCLUDE    /home/limt/moveue.dat
     *  Entries are in terms of 100 tons and in the order of
     *  unit name, origin airfield and destination airfield
     /
     UnitA.XDAT.FFTJ = 186.77
     UnitB.TYFR.FFTJ = 6.92
     UnitC.XDAT.FFTJ = 63.23
     UnitD.TMKH.FFTJ = 114.94
     UnitE.TYFR.UGZX = 663.69
     UnitF.TMKH.UGZX = 238.27
     UnitG.TYFR.UGZX = 5.03
     UnitH.XDAT.UGZX = 10.13
     UnitI.QFQE.UGZX = 5.03
     UnitJ.XDAT.UGZX = 10.13
     UnitK.TYFR.UGZX = 5.03
     UnitL.TYFR.UGZX = 4.91
     UnitM.TYFR.UGZX = 5.22
     UnitN.TYFR.UGZX = 5.03
     UnitO.TYFR.PKVV = 4.91
     UnitP.TYFR.PKVV = 5.22
     UnitQ.TMKH.PKVV = 10.13
     UnitR.TMKH.UGZX = 10.13
     UnitS.TMKH.UGZX = 10.13
     UnitT.XDAT.UGZX = 10.13
     /
     ;

     TABLE CARGOP(U,CC)
     *  Proportion of cargo types (bulk, over, out) belonging to
```

```
*  unit u moving from i to k.  Proportions for the different
*  types of cargo must add to 1.
INCLUDE    /home/limt/cargop.dat
               BULK   OVER   OUT
     UnitA    0.383  0.520  0.097
     UnitB    0.470  0.530  0.0
     UnitC    0.331  0.651  0.018
     UnitD    0.190  0.797  0.013
     UnitE    0.023  0.575  0.402
     UnitF    0.064  0.838  0.098
     UnitG    0.616  0.384  0.0
     UnitH    0.661  0.339  0.0
     UnitI    0.616  0.384  0.0
     UnitJ    0.661  0.339  0.0
     UnitK    0.616  0.384  0.0
     UnitL    0.658  0.342  0.0
     UnitM    0.665  0.335  0.0
     UnitN    0.616  0.384  0.0
     UnitO    0.616  0.384  0.0
     UnitP    0.658  0.342  0.0
     UnitQ    0.661  0.339  0.0
     UnitR    0.661  0.339  0.0
     UnitS    0.661  0.339  0.0
     UnitT    0.661  0.339  0.0
     ;

     PARAMETER MOVEPAX(U,I,K)    units' troop movement requirements
INCLUDE    /home/limt/movepax.dat
*  Entries are in terms of 100 men and in the order of
*  unit name, origin airfield and destination airfield
     /
     UnitA.XDAT.FFTJ = 126.98
     UnitB.TYFR.FFTJ = 13.84
     UnitC.XDAT.FFTJ = 52.59
     UnitD.TMKH.FFTJ = 97.76
     UnitE.TYFR.UGZX = 199.37
     UnitF.TMKH.UGZX = 190.82
     UnitG.TYFR.UGZX = 3.92
     UnitH.XDAT.UGZX = 8.46
     UnitI.QFQE.UGZX = 3.92
     UnitJ.XDAT.UGZX = 8.46
     UnitK.TYFR.UGZX = 3.92
     UnitL.TYFR.UGZX = 4.74
     UnitM.TYFR.UGZX = 3.72
     UnitN.TYFR.UGZX = 3.92
     UnitO.TYFR.PKVV = 4.74
     UnitP.TYFR.PKVV = 3.72
     UnitQ.TMKH.PKVV = 8.46
     UnitR.TMKH.UGZX = 8.46
     UnitS.TMKH.UGZX = 8.46
     UnitT.XDAT.UGZX = 8.46
     /

     PARAMETER ALD(U)   available load date for unit u
INCLUDE    /home/limt/ald.dat
     /
     UnitA   8
     UnitB   16
     UnitC   3
     UnitD   21
```

```
UnitE   3
UnitF   11
UnitG   1
UnitH   1
UnitI   2
UnitJ   2
UnitK   2
UnitL   2
UnitM   3
UnitN   3
UnitO   3
UnitP   3
UnitQ   4
UnitR   4
UnitS   4
UnitT   4
/

PARAMETER RDD(U)   required delivery date for unit u
INCLUDE    /home/limt/rdd.dat
/
UnitA   17
UnitB   20
UnitC   8
UnitD   26
UnitE   16
UnitF   19
UnitG   4
UnitH   4
UnitI   5
UnitJ   5
UnitK   5
UnitL   6
UnitM   6
UnitN   6
UnitO   6
UnitP   7
UnitQ   7
UnitR   7
UnitS   8
UnitT   8
/

SCALAR MAXLATE   maximum allowed lateness in days
INCLUDE    /home/limt/maxlate.dat
*  Maximum allowed lateness for delivery in days
/ 4 /
;

TABLE LATEPEN(U,C)  lateness penalty per day by unit and cargo
INCLUDE    /home/limt/latepen.dat
*  Late penalty for unit equipment should be measured in terms
*  of per 100 ton per day.  Late penalty for PAX should be
*  measured in terms of per 100 PAX per day.
        UE      PAX
UnitA   0.005   0.008
UnitB   0.14    0.072
UnitC   0.016   0.019
UnitD   0.009   0.010
UnitE   0.002   0.005
```

```
UnitF   0.004   0.005
UnitG   0.20    0.255
UnitH   0.197   0.236
UnitI   0.199   0.255
UnitJ   0.197   0.236
UnitK   0.199   0.255
UnitL   0.204   0.211
UnitM   0.192   0.269
UnitN   0.199   0.255
UnitO   0.204   0.211
UnitP   0.192   0.269
UnitQ   0.197   0.236
UnitR   0.197   0.236
UnitS   0.197   0.236
UnitT   0.197   0.236
;
PARAMETER NOGOPEN(U,C)  penalty for not fulfilling requirement ;
*  NOGOPEN should be larger than (MAXLATE x LATEPEN) for the
*  respective unit and cargo type.  This is for consistency or
*  else the LP may choose not to send instead of sending the
*  cargo late.
INCLUDE    /home/limt/nogopen.dat
NOGOPEN(U,C) = 2 * MAXLATE * LATEPEN(U,C)
;
*+++++++++++++++++++++++  CARGO DATA  +++++++++++++++++++++++
*
PARAMETER UESQFT(U)   ave. cargo space (in 1000 sq. ft.) per 100
*                     tons of unit u's cargo
INCLUDE    /home/limt/uesqft.dat
*  Entries are in terms of 1000 sq. ft. per 100 ton
/
UnitA   2.7
UnitB   2.6
UnitC   2.9
UnitD   3.0
UnitE   2.3
UnitF   3.1
UnitG   2.4
UnitH   2.4
UnitI   2.4
UnitJ   2.4
UnitK   2.4
UnitL   2.4
UnitM   2.4
UnitN   2.4
UnitO   2.4
UnitP   2.4
UnitQ   2.4
UnitR   2.4
UnitS   2.4
UnitT   2.4
/
SCALAR PAXWT   ave. wt (in 100 tons) of 100 troops  / 0.2 /;
*  Average PAX weight is set at 400 lbs or 0.2 stons inclusive of
*  personal equipment.  Therefore, average weight of 100 PAX is
*  0.2 hundred stons.
*++++++++++++++++++++++  AIRCRAFT DATA  +++++++++++++++++++++++++
```

```

PARAMETER SUPPLY(A,T)   no. of new aircraft made available on day T
INCLUDE    /home/limt/acsupply.dat
*  SUPPLY(A,T) represents additional number of aircraft (A) that
*  are first made available for use at time period (T).
/
C5.DAY1 = 10
C5.DAY6 = 30
C5.DAY11 = 40
C17.DAY1 = 2
C17.DAY6 = 6
C17.DAY11 = 8
C141.DAY1 = 20
C141.DAY6 = 60
C141.DAY11 = 80
C130.DAY1 = 20
C130.DAY6 = 60
C130.DAY11 = 80
747P.DAY6 = 10
747P.DAY11 = 30
747P.DAY16 = 20
747C.DAY6 = 5
747C.DAY11 = 25
747C.DAY16 = 50
DC10.DAY6 = 5
DC10.DAY11 = 25
DC10.DAY16 = 50
/
;

SET ACSIZE(A,AB)   aircraft body type
INCLUDE    /home/limt/acsize.dat
/
C5.WB
C17.GM
C141.NB
C130.TT
747P.WB
747C.WB
DC10.WB
/
;

TABLE ACCARGO(A,CC)   aircraft and cargo class matching
INCLUDE    /home/limt/accargo.dat
*  An entry of 1.0 represents compatibility
        BULK    OVER    OUT
C5      1.0     1.0     1.0
C17     1.0     1.0     1.0
C141    1.0     1.0     0.0
C130    1.0     1.0     0.0
747P    0.0     0.0     0.0
747C    1.0     0.0     0.0
DC10    0.0     0.0     0.0
;

PARAMETER MAXPAX(A)   troop carriage capacity (in 100s) of aircraft
INCLUDE    /home/limt/acmaxpax.dat
*  Entries are in terms of 100s of men
/
```

```
C5      0.73
C17     0.54
C141    1.43
C130    0.44
747P    4.02
747C    0.0
DC10    2.79
/
;

PARAMETER PAXSQFT(A)    cargo space (in 1000 sq. ft.) occupied by
*                       100 PAX
INCLUDE     /home/limt/paxsqft.dat
*  Entries are in terms of 1000 sq. ft. per 100 PAX
*  C5 PAX passenger seats upstairs and does not consume cargo space
*  CRAF PAX haulers have 0 sq. ft. per PAX and have 0 sq. ft. of
*  cargo space.
/
C5      0.0
C17     0.7
C141    0.7
C130    0.7
747P    0.0
747C    0.0
DC10    0.0
/
;

PARAMETER ACSQFT(A)    aircraft cargo space (in 1000 sq. ft.)
INCLUDE     /home/limt/acsqft.dat
*  Entries are in terms of 1000 sq. ft.
*  CRAF PAX haulers have 0 sq. ft. of cargo space.
/
C5     2.562
C17    1.533
C141   1.043
C130   0.452
747P   0.0
747C   2.772
DC10   0.0
/
;

PARAMETER LOADEFF(A)    loading efficiency for aircraft type
INCLUDE     /home/limt/loadeff.dat
*  Loading Efficiency gives the proportion of cargo space that
*  could be actually filled.  Loading Efficiency does not apply
*  to CRAF PAX haulers which have 0 sq. ft of cargo space.
/
C5      0.8
C17     0.8
C141    0.8
C130    0.8
747P    0.0
747C    1.0
DC10    0.0
/
;

PARAMETER SPD(A)    aircraft block speed in knots
```

```
INCLUDE     /home/limt/acspeed.dat
/
C5      419
C17     440
C141    397
C130    215
747P    450
747C    450
DC10    450
/
;

TABLE GTIME(A,GA)   aircraft ground activity duration in hrs
INCLUDE     /home/limt/gtime.dat
        ONLD    ENR    OFFLD
C5      3.25    2.25   3.25
C17     2.25    2.25   2.25
C141    2.25    2.25   2.25
C130    1.5     1.5    1.5
747P    3.0     2.0    3.0
747C    4.0     2.0    3.0
DC10    3.0     2.0    3.0
;

PARAMETER URATE(A)   aircraft planned utilization rate
*  Gives the planning norm for aircraft utilization.
INCLUDE     /home/limt/urate.dat
*   Entries are in 100 hrs per aircraft per day
/
C5     0.109
C17    0.152
C141   0.102
C130   0.054
747P   0.10
747C   0.10
DC10   0.10
/
;

*++++++++++++++++  AIRCRAFT RANGE-PAYLOAD DATA  +++++++++++++++++
*  The following tables allow for the computation of critical
*  payload for a particular route.  The entries in ACRANGE and
*  ACLOAD (for a rangeband and aircraft pair) give the range and
*  respective critical payload data for the aircraft.  These data
*  are used to interpolate the critical payload for a given range.

SET RANGEBAND  / 1*7 /;

TABLE ACRANGE(A,RANGEBAND)   aircraft range points
INCLUDE     /home/limt/acrange.dat
          1      2      3       4       5       6       7
C5      2000   2500   3000    3500    4000    4500   10000
C17     2400   3400   4200   10000       0       0       0
C141    2000   2500   3000    3500    4000    4500   10000
C130    2000   4200   4800   10000       0       0       0
747P    4450   6200  10000       0       0       0       0
747C    2425   3000   3500    6000       0       0       0
DC10    3000   3500   6000   10000       0       0       0
;

```

```
TABLE ACLOAD(A,RANGEBAND)   aircraft payloads (in 100 tons) at range
INCLUDE    /home/limt/acload.dat
*  Entries are in terms of 100 tons
              1       2       3        4        5        6        7
C5       1.127   0.999   0.873    0.757    0.630    0.506        0
C17      0.800   0.650     0        0        0        0          0
C141     0.344   0.299   0.259    0.203    0.161    0.114        0
C130     0.215   0.085     0        0        0        0          0
747P     0.64      0       0        0        0        0          0
747C     1.286   1.216   1.116      0        0        0          0
DC10     0.44      0       0        0        0        0          0
;

PARAMETER SLOPE(A,RANGEBAND)   slopes for interpolation;
*  Slopes give the change in payload from rangeband i-1 to
*  rangeband i.

SLOPE(A,RANGEBAND) =
    0$(ORD(RANGEBAND) EQ 1) +
    (  (ACLOAD(A,RANGEBAND-1)-ACLOAD(A,RANGEBAND))/
            (1$(ACRANGE(A,RANGEBAND) EQ 0)+
             (ACRANGE(A,RANGEBAND)-ACRANGE(A,RANGEBAND-1))
            $(ACRANGE(A,RANGEBAND) GT 0)) )$(ORD(RANGEBAND) GT 1);

*++++++++++++++++++++++  AIRFIELD DATA  ++++++++++++++++++++++++

TABLE CRD(AF,COORDS)   airfield coordinates in decimals
INCLUDE    /home/limt/afcoord.dat
             LAT      LON
QFQE     52.4       0.5
TMKH     35.2     -79.0
TYFR     49.4       7.6
XDAT     38.3    -121.9
FFTJ     26.3      50.2
UGZX     24.7      46.7
PKVV     20.7      58.9
KNMD     21.3    -157.9
FXSB     61.25   -149.8
WWYK     35.4     -97.4
NNGX     42.36    -71.01
UTKY     37.62   -122.4
FJXT     39.1     -75.5
ZNRE     35.8     139.4
HTDS     51.5       0.7
FGDC     -7.3      72.4
XBGX     40.49     -3.46
;

TABLE MOGCAP(AF,AB)   MOG capacity at airfield
*  MOG in essence represents the airfield's aircraft handling
*  capacity.  MOG capacity depends on the aircraft body
*  type.  MOG figures are based on a host of factors such as
*  ramp space, fuel availability, MHE, servicing, reception
*  capability and contention with collocated combat units.
INCLUDE    /home/limt/mogcap.dat
            WB    NB    GM    TT
QFQE         5     9     9
TMKH        17    32    32
TYFR         8    22    22
XDAT        23    41    41
```

```
FFTJ   10   14   15
UGZX    6   10   13
PKVV    1    3    3
KNMD   30   41   41
FXSB    8   16   16
WWYK    8   16   16
NNGX    7    7    7
UTKY    7    7    7
FJXT    9   14   14
ZNRE   10   20   20
HTDS    3   12   12
FGDC    2    5    5
XBGX   10   12   12
;

* set all tactical MOG availabilities to NB MOG/.75

  MOGCAP(AF,'TT') = MOGCAP(AF,'NB')/.75;

SCALAR MOGEFF   efficiency factor for MOG usage
INCLUDE    /home/limt/mogeff.dat
*  MOG efficiency factor is to cater for the fact that MOG capacity
*  cannot be achieved due to the stochastic nature of ground time.
/ 0.9 /
;

*+++++++++++++++++++++  ROUTE PARAMETERS  +++++++++++++++++++++

*  The following equations are used to compute the distance between
*  any two airfields.

ALIAS (AF,AFP);

PARAMETERS FX(AF,AFP)    result of sin cos argument of acos fcn
           DIST(AF,AFP)  distance between airfields;

SCALAR DTOR   conversion factor from degrees to radians ;
  DTOR = 0.017453293;

FX(AF,AFP) =
        COS(DTOR*CRD(AF,'LAT'))*COS(DTOR*CRD(AFP,'LAT'))*
             COS(DTOR*(CRD(AF,'LON')-CRD(AFP,'LON')))  +
             SIN(DTOR*CRD(AF,'LAT'))*SIN(DTOR*CRD(AFP,'LAT'));

DIST(AF,AFP)$(ORD(AF) NE ORD(AFP))
              = 3437*((ARCTAN(SQRT(1-SQR(FX(AF,AFP)))/
                FX(AF,AFP)))$(FX(AF,AFP) GT 0) +
                (3.141592653+ARCTAN(SQRT(1-SQR(FX(AF,AFP)))
                /FX(AF,AFP)))$(FX(AF,AFP) LT 0));

PARAMETER MAXLEG(I,K,E1,E2,E3)   longest leg of each route ;
  MAXLEG(I,K,E1,E2,E3) =
              MAX(DIST(I,E1),DIST(E1,E2),DIST(E2,E3),DIST(E3,K));

PARAMETER MAXLOAD(A,I,K,E1,E2,E3)  maximum payload on longest leg ;
*  Gives maximum payload of an aircraft type on a particular route
  MAXLOAD(A,I,K,E1,E2,E3) $ VROUTEX(A,I,K,E1,E2,E3)  =
       ACLOAD(A,'1')$(MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'1')) +
 (ACLOAD(A,'1')+SLOPE(A,'2')*(ACRANGE(A,'1')-MAXLEG(I,K,E1,E2,E3)))
               $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'1') AND
```

```
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'2'))      +
 (ACLOAD(A,'2')+SLOPE(A,'3')*(ACRANGE(A,'2')-MAXLEG(I,K,E1,E2,E3)))
                 $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'2') AND
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'3'))      +
 (ACLOAD(A,'3')+SLOPE(A,'4')*(ACRANGE(A,'3')-MAXLEG(I,K,E1,E2,E3)))
                 $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'3') AND
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'4'))      +
 (ACLOAD(A,'4')+SLOPE(A,'5')*(ACRANGE(A,'4')-MAXLEG(I,K,E1,E2,E3)))
                 $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'4') AND
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'5'))      +
 (ACLOAD(A,'5')+SLOPE(A,'6')*(ACRANGE(A,'5')-MAXLEG(I,K,E1,E2,E3)))
                 $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'5') AND
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'6'))      +
 (ACLOAD(A,'6')+SLOPE(A,'7')*(ACRANGE(A,'6')-MAXLEG(I,K,E1,E2,E3)))
                 $(MAXLEG(I,K,E1,E2,E3) GE ACRANGE(A,'6') AND
                   MAXLEG(I,K,E1,E2,E3) LE ACRANGE(A,'7'))      ;

PARAMETER CTTOE1(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to travel from origin airfield
*  (I) to enroute airfield (E1) along the route specified inclusive
*  of ground time.
  CTTOE1(A,I,K,E1,E2,E3) $VROUTEX(A,I,K,E1,E2,E3)  =
  GTIME(A,'ONLD') + (DIST(I,E1)/SPD(A));

PARAMETER CTTOE2(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to travel from origin airfield
*  to enroute airfield (E2) along the route specified inclusive of
*  ground time.
  CTTOE2(A,I,K,E1,E2,E3)  $VROUTEX(A,I,K,E1,E2,E3) =
  CTTOE1(A,I,K,E1,E2,E3) +
               (GTIME(A,'ENR') + (DIST(E1,E2)/SPD(A)))$DIST(E1,E2);

PARAMETER CTTOE3(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to travel from origin airfield
*  to enroute airfield (E3) along the route specified.
  CTTOE3(A,I,K,E1,E2,E3) $VROUTEX(A,I,K,E1,E2,E3)  =
  CTTOE2(A,I,K,E1,E2,E3) +
               (GTIME(A,'ENR') + (DIST(E2,E3)/SPD(A)))$DIST(E2,E3);

PARAMETER CTTOK(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to travel from origin airfield
*  to destination airfield (K) along the route specified.
  CTTOK(A,I,K,E1,E2,E3) $VROUTEX(A,I,K,E1,E2,E3)  =
  CTTOE3(A,I,K,E1,E2,E3) +
               (GTIME(A,'ENR') + (DIST(E3,K)/SPD(A)))$DIST(E3,K) ;

PARAMETER FLTTIME(A,I,K,E1,E2,E3)  flight time (in 100 hrs) ;
*  Gives the total flying hours consumed by an aircraft along a
*  specified route.
  FLTTIME(A,I,K,E1,E2,E3) $VROUTEX(A,I,K,E1,E2,E3)  =
  (DIST(I,E1) + DIST(E1,E2) + DIST(E2,E3)
                         + DIST(E3,K)) / ( SPD(A) * 100 ) ;

PARAMETER RCTTOE3(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to recover from destination
*  airfield (K) to enroute airfield (E3) along the specified route
*  inclusive of ground time.  Note: (a) the route sequence is now
*  from K to E3 to E2 to E1 to I.  (b) the ordering of indices is
*  preserved as such, as recommended by GAMS.
  RCTTOE3(A,I,K,E1,E2,E3)  $VROUTEY(A,I,K,E1,E2,E3) =
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  GTIME(A,'OFFLD') + (DIST(E3,K)/SPD(A)) ;

PARAMETER RCTTOE2(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to recover from destination
*  airfield (K) to enroute airfield (E2) along the specified route
*  inclusive of ground time.
  RCTTOE2(A,I,K,E1,E2,E3)  $VROUTEY(A,I,K,E1,E2,E3) =
  RCTTOE3(A,I,K,E1,E2,E3) +
          (GTIME(A,'ENR') + (DIST(E2,E3)/SPD(A)))$DIST(E2,E3);

PARAMETER RCTTOE1(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to recover from destination
*  airfield (K) to enroute airfield (E1) along the specified route
*  inclusive of ground time.
  RCTTOE1(A,I,K,E1,E2,E3) $VROUTEY(A,I,K,E1,E2,E3)  =
  RCTTOE2(A,I,K,E1,E2,E3) +
            (GTIME(A,'ENR') + (DIST(E1,E2)/SPD(A)))$DIST(E1,E2);

PARAMETER RCTTOI(A,AF,AF,AF,AF,AF) ;
*  Cumulative time (in hours) taken to recover from destination
*  airfield (K) to origin airfield (I) along the specified route
*  inclusive of ground time.
  RCTTOI(A,I,K,E1,E2,E3)  $VROUTEY(A,I,K,E1,E2,E3) =
  RCTTOE1(A,I,K,E1,E2,E3) +
             (GTIME(A,'ENR') + (DIST(I,E1)/SPD(A)))$DIST(I,E1);

PARAMETER MOGREQ(AF,A)   normalized (to NB) MOG requirement ;
*  Normalized MOG requirement for an aircraft type to that of a
*  narrow body aircraft for the airfield.
  MOGREQ(AF,A) = MOGCAP(AF,'NB') /
                 ( MOGCAP(AF,'WB')$ACSIZE(A,'WB') +
                   MOGCAP(AF,'GM')$ACSIZE(A,'GM') +
                   MOGCAP(AF,'TT')$ACSIZE(A,'TT') +
                   MOGCAP(AF,'NB')$ACSIZE(A,'NB') );

*+++++++++++++++++++++++  LP VARIABLES  +++++++++++++++++++++++++

INTEGER VARIABLES

 X(U,A,AF,AF,AF,AF,AF,T)   number of airlift missions(aircraft) for
*                           unit (U), by aircraft (A), on the route
*                           specified with start time (T).

  Y(A,AF,AF,AF,AF,AF,T)   no. of aircraft (A) recovered to base (I)
*                         on the route specified with start
*                         time (T).

  ALLOT(A,I,T)   new aircraft made available allotted to base (I).

  H(A,I,T)   number of aircraft (A) saved for use at time T+1,
*            at origin base (I), an end-of-period inventory.

  HP(A,K,T)   number of aircraft (A) that will start recovery ;
*             from destination (K) in the next period instead of
*             the current period.

POSITIVE VARIABLES

  TONSUE(U,A,I,K,E1,E2,E3,T)   unit U's equipment (in 100 tons)
*                              airlifted by aircraft (A) on the
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*                                 specified route with start time (T).

   TPAX(U,A,I,K,E1,E2,E3,T)    number (in 100s) of unit U's troops
*                              airlifted by aircraft (A), on the
*                              specified route with start time (T).

   UENOGO(U,I,K)     unit U's equipment (in 100 tons) not airlifted
*                    from the origin base (I) to destination (K)
*                    in the theater.

  PAXNOGO(U,I,K)   number (in 100s) of unit U's troops not airlifted;
*                  from the origin base (I) to destination (K)
*                  in the theater.

FREE VARIABLE
   Z   total penalty incurred from late deliveries and for not
*      fulfilling delivery requirement (undelivered cargoes).

*+++++++++++++++++++  DYNAMIC SET DECLARATION  ++++++++++++++++

SET DSETX(U,A,AF,AF,AF,AF,AF,T)   ;
*  Used to control the allowable combination of unit, aircraft,
*  route, and start time for the following decision variables:
*  X(U,A,I,K,E1,E2,E3,T), TONSUE(U,A,I,K,E1,E2,E3,T) and
*  TPAX(U,A,I,K,E1,E2,E3,T).  A valid combination implies that the
*  following be satisfied: Start time for delivery must be after an
*  unit's ALD and delivery date must be before the RDD plus the
*  maximum allowed lateness.  There is movement requirement.
*  Maximum aircraft payload for the route must be greater than 25%
*  its full load capability; this is for cost efficiency.  Supply
*  of aircraft type to date must be greater than 0.
   DSETX(U,VROUTEX(A,I,K,E1,E2,E3),T) = YES $(
      (ORD(T) GE ALD(U)) AND
      (ORD(T) LE (RDD(U) - ROUND(CTTOK(VROUTEX)/24) + MAXLATE))
     AND (1$MOVEUE(U,I,K) OR 1$MOVEPAX(U,I,K))
     AND (1$(MAXLOAD(VROUTEX) GT (0.25 * ACLOAD(A,"1")) ))
     and SUM (TP$(ORD(TP) LE ORD(T)), SUPPLY(A,TP))
     ) ;

SET DSETY(A,AF,AF,AF,AF,AF,T)   ;
*  Used to control the allowable combination of aircraft,
*  route, and start time for the decision variable
*  Y(U,A,I,K,E1,E2,E3,T).  An allowable combination is one
*  in which the aircraft-route is compatible and that the supply
*  of aircraft type to date is greater than 0.
   DSETY(VROUTEY(A,I,K,E1,E2,E3),T) = YES $(
     SUM (TP$(ORD(TP) LE ORD(T)), SUPPLY(A,TP))
     );

*+++++++++++++++++++ LP EQUATION DEFINITIONS ++++++++++++++++++++

EQUATIONS

   OBJFUN   define objective function
   REQMTUE(U,I,K)   movement requirement for UE
   OUTREQMT(U,I,K)   out-sized cargo requirement
   OVERREQMT(U,I,K)   over-sized cargo requirement
   REQMTPAX(U,I,K)  movement requirement for troops
   ACBALI(A,I,T)   aircraft balance equation at origins
   ACALLOT(A,T)   aircraft allocation balance equation
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   ACBALK(A,K,T)   aircraft balance equation at destinations
   ACWEIGHT(U,A,I,K,E1,E2,E3,T)  aircraft payload limitation
   ACSPACE(U,A,I,K,E1,E2,E3,T)  aircraft cargo space limitation
   ACPAX(U,A,I,K,E1,E2,E3,T)  aircraft PAX carriage limitation
   ACURATE(A)   utilization rate constraint
   MOGUTILITY(AF,T)  handling capacity of airfields ;

*++++++++++++++++++++  OBJECTIVE FUNCTION  +++++++++++++++++++++++

OBJFUN..
  Z =E= SUM ( (U,A,I,K,E1,E2,E3,T) $DSETX(U,A,I,K,E1,E2,E3,T),
        (TONSUE(U,A,I,K,E1,E2,E3,T)$ACSQFT(A) * LATEPEN(U,'UE') *
         MAX(0, ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24)-RDD(U)) ) +
        (TPAX(U,A,I,K,E1,E2,E3,T) * LATEPEN(U,'PAX') *
         MAX(0, ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24)-RDD(U)) ))
  + SUM ( (U,I,K) $(1$MOVEUE(U,I,K) OR 1$MOVEPAX(U,I,K)),
        (UENOGO(U,I,K)*NOGOPEN(U,'UE')) +
        (PAXNOGO(U,I,K)*NOGOPEN(U,'PAX')) );

*+++++++++++++++  DEMAND SATISFACTION CONSTRAINTS  +++++++++++++++

*  Total tonnage (in 100 tons) of unit equipment delivered to the
*  theater by all aircraft types flying all routes over all time
*  periods plus total tonnage (in 100 tons) of equipment not
*  delivered must be greater than or equal to the movement
*  requirement for unit equipment.

REQMTUE(U,I,K) $MOVEUE(U,I,K)..
 SUM ( (A,E1,E2,E3) $ACCARGO(A,'BULK'),
  SUM ( T $DSETX(U,A,I,K,E1,E2,E3,T), TONSUE(U,A,I,K,E1,E2,E3,T)) )
 + UENOGO(U,I,K)  =G=  MOVEUE(U,I,K)  ;

*  Total tonnage (in 100 tons) of unit equipment carried by out-
*  sized cargo capable aircraft plus tonnage of unit equipment
*  not delivered (UENOGO) must be greater than or equal to the
*  movement requirement for out-sized cargo (given by the
*  proportion of out-sized cargo multiplied by the movement
*  requirement for unit equipment).
*
OUTREQMT(U,I,K) $MOVEUE(U,I,K)..
 SUM ( (A,E1,E2,E3) $ ACCARGO(A,'OUT'),
  SUM ( T $DSETX(U,A,I,K,E1,E2,E3,T), TONSUE(U,A,I,K,E1,E2,E3,T)) )
   + UENOGO(U,I,K) =G= CARGOP(U,'OUT') * MOVEUE(U,I,K) ;

*  Total tonnage (in 100 tons) of unit equipment carried by over-
*  sized cargo capable aircraft plus tonnage of unit equipment
*  not delivered (UENOGO) must be greater than or equal to the
*  movement requirement for over-sized and out-sized cargoes
*  (given by the proportion of out-sized cargo + proportion of
*  over-sized cargo multiplied by the movement requirement for
*  unit equipment).  This constraint is set up as such because an
*  out-sized carrier can be used to carry over-sized cargo.

OVERREQMT(U,I,K) $MOVEUE(U,I,K)..
 SUM ( (A,E1,E2,E3) $ACCARGO(A,'OVER'),
  SUM ( T $DSETX(U,A,I,K,E1,E2,E3,T), TONSUE(U,A,I,K,E1,E2,E3,T)) )
   + UENOGO(U,I,K)
     =G= ( CARGOP(U,'OVER') + CARGOP(U,'OUT') ) * MOVEUE(U,I,K) ;

*  Total number (in 100s) of troops airlifted to the theater plus
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*  those not airlifted must be greater than or equal to the
*  movement requirement for troops.

REQMTPAX(U,I,K) $MOVEPAX(U,I,K)..
 SUM ( (A,E1,E2,E3),
  SUM ( T $DSETX(U,A,I,K,E1,E2,E3,T),  TPAX(U,A,I,K,E1,E2,E3,T) ) )
 + PAXNOGO(U,I,K)  =G=  MOVEPAX(U,I,K)  ;

*+++++++++++++++++  AIRCRAFT BALANCE CONSTRAINTS  ++++++++++++++++

*  Aircraft balance constraint at origin airfields.  On each day,
*  the total number of aircraft assigned for airlift missions plus
*  aircraft inventoried must be equal to the number of aircraft
*  available from the last period plus new supply of a/c allocated
*  to the base and aircraft that return from previous missions.

ACBALI(A,I,T)..
   SUM ( (U,K,E1,E2,E3)$DSETX(U,A,I,K,E1,E2,E3,T),
          X(U,A,I,K,E1,E2,E3,T) ) + H(A,I,T)
    =E= H(A,I,T-1)$(ORD(T) GT 1) + ALLOT(A,I,T) $SUPPLY(A,T) +
        SUM ( (K,E1,E2,E3),
          SUM ( TP $(
           1$DSETY(A,I,K,E1,E2,E3,TP) AND
         1$((ORD(TP)+ROUND(RCTTOI(A,I,K,E1,E2,E3)/24)) EQ ORD(T))),
           Y(A,I,K,E1,E2,E3,TP) ) ) ;

*  The sum of aircraft (newly made available) allocated to the
*  different origin bases each day must be less than or equal
*  to the number of aircraft actually made available.

ACALLOT(A,T) $SUPPLY(A,T)..  SUM(I, ALLOT(A,I,T)) =L= SUPPLY(A,T) ;

*  Aircraft balance constraint at destination airfields.  On each
*  day, the number of each type of aircraft returning plus
*  those that will return in the next period from a destination
*  airfield must be equal to those waiting to return plus new
*  arrivals at the destination.

ACBALK(A,K,T)..
   SUM ((I,E1,E2,E3) $DSETY(A,I,K,E1,E2,E3,T),
     Y(A,I,K,E1,E2,E3,T)) + HP(A,K,T)
     =E= HP(A,K,T-1)$(ORD(T) GT 1) +
       SUM ( (U,I,E1,E2,E3),
         SUM (
          TP$( ((ORD(TP)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24)) EQ ORD(T))
                 AND 1$DSETX(U,A,I,K,E1,E2,E3,TP)) ,
                X(U,A,I,K,E1,E2,E3,TP) ) )  ;

*++++++++++++  AIRCRAFT PHYSICAL LIMITATION CONSTRAINTS  ++++++++++

*  Payload limitation:  Total weight (equipment and men) carried
*  by aircraft (A) on each route must be less than the critical
*  payload for the route multiplied by the number of aircraft
*  assigned for airlift missions.

ACWEIGHT(U,A,I,K,E1,E2,E3,T)$DSETX(U,A,I,K,E1,E2,E3,T)..
   TONSUE(U,A,I,K,E1,E2,E3,T) + PAXWT*TPAX(U,A,I,K,E1,E2,E3,T)
 =L= MAXLOAD(A,I,K,E1,E2,E3) * X(U,A,I,K,E1,E2,E3,T)  ;

*  Cargo Space limitation:  The total cargo space taken up by men
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*  and equipment carried by aircraft (A) on each route must be
*  less than the cargo space of the aircraft multiplied by the
*  aircraft loading efficiency and the number of aircraft
*  assigned for airlift missions.

ACSPACE(U,A,I,K,E1,E2,E3,T)
    $(ACSQFT(A) $DSETX(U,A,I,K,E1,E2,E3,T) )..
      ( PAXSQFT(A) * TPAX(U,A,I,K,E1,E2,E3,T) ) +
      ( UESQFT(U) * TONSUE(U,A,I,K,E1,E2,E3,T) )
        =L= ACSQFT(A) * LOADEFF(A) * X(U,A,I,K,E1,E2,E3,T) ;

*  PAX carriage limitation:  The total number of troops carried by
*  aircraft (A) on each route must not be greater than the troop
*  carriage capacity of the aircraft type multiplied by the number
*  of aircraft assigned for airlift missions.

ACPAX(U,A,I,K,E1,E2,E3,T)$DSETX(U,A,I,K,E1,E2,E3,T)..
  TPAX(U,A,I,K,E1,E2,E3,T) =L= MAXPAX(A) * X(U,A,I,K,E1,E2,E3,T) ;

*  Cargo space limitation.

*+++++++++++++ AIRCRAFT UTILIZATION RATE CONSTRAINTS ++++++++++++

*  The total number of flying hours (in 100s) consumed by each
*  aircraft type must be less than the utilization rate (in 100 hrs
*  per aircraft per day) times the number of aircraft initially
*  made available on day (T) times the remaining time periods where
*  these aircraft could be used.  The productive time periods for
*  an aircraft made vailable on day (T) is equal to the total time
*  periods (CARD(T)) plus 1 minus ORD(T).  For example, if the
*  total time periods of concern is 10, then an aircraft initially
*  made available on day 1 could be used for 10 days.

ACURATE(A)..
  SUM ( (U,I,K,E1,E2,E3,T) $DSETX(U,A,I,K,E1,E2,E3,T),
        X(U,A,I,K,E1,E2,E3,T) * FLTTIME(A,I,K,E1,E2,E3) ) +
  SUM ( (I,K,E1,E2,E3,T) $DSETY(A,I,K,E1,E2,E3,T),
        Y(A,I,K,E1,E2,E3,T) * FLTTIME(A,I,K,E1,E2,E3) )
    =L=  SUM ( T $SUPPLY(A,T) ,
           URATE(A) * ( CARD(T)+1-ORD(T) ) * SUPPLY(A,T)  );

*++++ AIRCRAFT HANDLING CAPACITY OF AIRFIELD (MOG CONSTRAINT)  ++++

*  These constraints model the throughput or handling capacity of
*  an airfield; i.e., it will limit the number of aircraft using
*  the airfield each day.  As an airfield can serve as an origin,
*  enroute, or destination, the total MOG consumed for each day
*  would be a sum of individual consumptions.  This total must not
*  be greater than the MOG effciency factor multiplied by the MOG
*  capacity (scaled to narrow body aircraft for comparison) of that
*  airfield.  A MOG efficiency factor is used as it is recognised
*  that it is virtually impossible for an airfield to be running
*  at full capacity for the whole day given the stochastic nature
*  aircraft ground times.  Unless aircraft can be sequenced to
*  arrive at an airfield precisely one after another, congestion
*  can occurs and the effective MOG utilization will be below the
*  MOG capacity of the airfield.  As an origin airfield, MOG
*  consumed is equal to the total number of aircraft assigned for
*  airlift missions scaled by the MOGREQ (normalize MOG
*  requirement of aircraft) and the proportion of time (per day)
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*  spent on a MOG spot.  Proportion of time spent is equal to the
*  on-load time divided by 24 in this case.  As an enroute
*  airfield, the MOG consumed is equal to the total number of
*  aircraft making enroute stops scaled by the MOGREQ factor and
*  the proportion of time spent on a MOG spot (enroute ground time
*  divided by 24).  The MOG consumption when the airfield serves
*  as a destination is computed in a similar manner except that
*  the proportion of time spent is equal to the off-load time
*  divided by 24.  To prevent double counting of MOG consumption,
*  conditional checks are done for enroute airfields.  These are:
*    i.   Valid combination of indices (member of DSETX or DSETY)
*    ii.  Time of arrival is the period of concern
*    iii. The aircraft came from somewhere (distance between the
*         previous and current airfield is not equal to 0)
*    iv.  Time to enroute airfield is not equal to time to origin
*         or destination airfield

MOGUTILITY(AF,T)..

  SUM ( (U,A,K,E1,E2,E3) $DSETX(U,A,AF,K,E1,E2,E3,T) ,
    X(U,A,AF,K,E1,E2,E3,T) * MOGREQ(AF,A) * GTIME(A,'ONLD') / 24 )
*  MOG utilization when used as an origin airfield (I)

  +
  SUM ( (U,A,I,K,E2,E3,TP) $(
    1$DSETX(U,A,I,K,AF,E2,E3,TP) AND
    1$(ORD(TP)+ROUND(CTTOE1(A,I,K,AF,E2,E3)/24) EQ ORD(T)) AND
    1$DIST(I,AF) AND
    1$(CTTOE1(A,I,K,AF,E2,E3) NE CTTOK(A,I,K,AF,E2,E3)) ),
    X(U,A,I,K,AF,E2,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )

+ SUM ( (A,I,K,E2,E3,TP) $(
    1$DSETY(A,I,K,AF,E2,E3,TP) AND
    1$(ORD(TP)+ROUND(RCTTOE1(A,I,K,AF,E2,E3)/24) EQ ORD(T)) AND
    1$DIST(AF,E2) AND
    1$(RCTTOE1(A,I,K,AF,E2,E3) NE RCTTOI(A,I,K,AF,E2,E3)) ) ,
    Y(A,I,K,AF,E2,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
*  MOG utilization when used as an E1 airfield

  +
  SUM ( (U,A,I,K,E1,E3,TP) $(
    1$DSETX(U,A,I,K,E1,AF,E3,TP) AND
    1$(ORD(TP)+ROUND(CTTOE2(A,I,K,E1,AF,E3)/24) EQ ORD(T)) AND
    1$DIST(E1,AF) AND
    1$(CTTOE2(A,I,K,E1,AF,E3) NE CTTOK(A,I,K,E1,AF,E3)) ),
    X(U,A,I,K,E1,AF,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )

+  SUM ( (A,I,K,E1,E3,TP) $(
    1$DSETY(A,I,K,E1,AF,E3,TP) AND
    1$(ORD(TP)+ROUND(RCTTOE2(A,I,K,E1,AF,E3)/24) EQ ORD(T)) AND
    1$DIST(AF,E3) AND
    1$(RCTTOE2(A,I,K,E1,AF,E3) NE RCTTOI(A,I,K,E1,AF,E3)) ),
    Y(A,I,K,E1,AF,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
*  MOG utilization when used as an E2 airfield

  +
  SUM ( (U,A,I,K,E1,E2,TP) $(
    1$DSETX(U,A,I,K,E1,E2,AF,TP) AND
    1$(ORD(TP)+ROUND(CTTOE3(A,I,K,E1,E2,AF)/24) EQ ORD(T)) AND
    1$DIST(E2,AF) AND
```

```
     1$(CTTOE3(A,I,K,E1,E2,AF) NE CTTOK(A,I,K,E1,E2,AF)) ),
     X(U,A,I,K,E1,E2,AF,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )

+  SUM ( (A,I,K,E1,E2,TP) $(
     1$DSETY(A,I,K,E1,E2,AF,TP) AND
     1$(ORD(TP)+ROUND(RCTTOE3(A,I,K,E1,E2,AF)/24) EQ ORD(T)) AND
     1$DIST(AF,K) AND
     1$(RCTTOE3(A,I,K,E1,E2,AF) NE RCTTOI(A,I,K,E1,E2,AF)) ),
     Y(A,I,K,E1,E2,AF,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
*  MOG utilization when used as an E3 airfield

   +
   SUM ( (U,A,I,E1,E2,E3,TP) $(
     1$DSETX(U,A,I,AF,E1,E2,E3,TP) AND
     1$(ORD(TP)+ROUND(CTTOK(A,I,AF,E1,E2,E3)/24) EQ ORD(T)) ),
    X(U,A,I,AF,E1,E2,E3,TP) * MOGREQ(AF,A) * GTIME(A,'OFFLD') / 24)
*  MOG utilization when used as a destination airfield (K)

   =L= MOGEFF * MOGCAP(AF,'NB') ;


MODEL AIRLIFT  /ALL/;

SOLVE AIRLIFT using RMIP minimizing Z ;
```

Include File Summary

| GLOBAL | TYPE | LOCAL | FILE NAME |
|---|---|---|---|
| 0 | INPUT | 0 | /home/limt/airlift6.gms |
| 24 | INCLUDE | 24 | ./home/limt/unitname.dat |
| 49 | INCLUDE | 27 | ./home/limt/acname.dat |
| 61 | INCLUDE | 30 | ./home/limt/craf.dat |
| 69 | INCLUDE | 33 | ./home/limt/milac.dat |
| 89 | INCLUDE | 47 | ./home/limt/periods.dat |
| 107 | INCLUDE | 59 | ./home/limt/afname.dat |
| 130 | INCLUDE | 62 | ./home/limt/orgname.dat |
| 139 | INCLUDE | 65 | ./home/limt/destname.dat |
| 147 | INCLUDE | 68 | ./home/limt/e1name.dat |
| 162 | INCLUDE | 71 | ./home/limt/e2name.dat |
| 175 | INCLUDE | 74 | ./home/limt/e3name.dat |
| 190 | INCLUDE | 81 | ./home/limt/vroutex.set |
| 237 | INCLUDE | 84 | ./home/limt/vroutey.set |
| 267 | INCLUDE | 91 | ./home/limt/moveue.dat |
| 298 | INCLUDE | 98 | ./home/limt/cargop.dat |
| 323 | INCLUDE | 102 | ./home/limt/movepax.dat |
| 350 | INCLUDE | 105 | ./home/limt/ald.dat |
| 375 | INCLUDE | 108 | ./home/limt/rdd.dat |
| 400 | INCLUDE | 111 | ./home/limt/maxlate.dat |
| 407 | INCLUDE | 115 | ./home/limt/latepen.dat |
| 439 | INCLUDE | 123 | ./home/limt/nogopen.dat |
| 445 | INCLUDE | 128 | ./home/limt/uesqft.dat |
| 478 | INCLUDE | 138 | ./home/limt/acsupply.dat |
| 507 | INCLUDE | 142 | ./home/limt/acsize.dat |
| 520 | INCLUDE | 146 | ./home/limt/accargo.dat |
| 533 | INCLUDE | 150 | ./home/limt/acmaxpax.dat |
| 547 | INCLUDE | 154 | ./home/limt/paxsqft.dat |
| 564 | INCLUDE | 158 | ./home/limt/acsqft.dat |
| 579 | INCLUDE | 162 | ./home/limt/loadeff.dat |

```
     595 INCLUDE          166  ./home/limt/acspeed.dat
     608 INCLUDE          170  ./home/limt/gtime.dat
     621 INCLUDE          175  ./home/limt/urate.dat
     644 INCLUDE          188  ./home/limt/acrange.dat
     656 INCLUDE          192  ./home/limt/acload.dat
     682 INCLUDE          209  ./home/limt/afcoord.dat
     709 INCLUDE          218  ./home/limt/mogcap.dat
     735 INCLUDE          226  ./home/limt/mogeff.dat


COMPILATION TIME     =        0.680 SECONDS        VERID AIX-00-064

Model Statistics    SOLVE AIRLIFT USING RMIP FROM LINE 1218

MODEL STATISTICS

BLOCKS OF EQUATIONS       13     SINGLE EQUATIONS      6349
BLOCKS OF VARIABLES       10     SINGLE VARIABLES      8723
NON ZERO ELEMENTS      38614     DISCRETE VARIABLES    5500

GENERATION TIME      =       42.590 SECONDS


EXECUTION TIME       =       44.700 SECONDS        VERID AIX-00-064

STEP SUMMARY:        0.010 STARTUP
                     0.680 COMPILATION
                    44.700 EXECUTION
                     0.090 CLOSEDOWN
                    45.480 TOTAL SECONDS


Solution Report     SOLVE AIRLIFT USING RMIP FROM LINE 1218


               S O L V E     S U M M A R Y

     MODEL   AIRLIFT              OBJECTIVE  Z
     TYPE    RMIP                 DIRECTION  MINIMIZE
     SOLVER  OSL                  FROM LINE  1218

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE               37.0139

 RESOURCE USAGE, LIMIT          28.690    18000.000
 ITERATION COUNT, LIMIT       3001        400000

 OSL Release 2,  GAMS Link level 3  ---  AIX RS/6000  1.3.045-017

 Work space allocated            --    5.54 Mb


**** REPORT SUMMARY :          0     NONOPT
                               0 INFEASIBLE
                               0  UNBOUNDED


EXECUTION TIME       =        0.230 SECONDS        VERID AIX-00-064
```

```
USER: Operations Research Department                    G940405-1442AX-AIX
      Naval Postgraduate School

**** FILE SUMMARY

INPUT      /home/limt/airlift6.gms
OUTPUT     /home/limt/airlift6.lst
SAVE       /home/limt/final.g0?

**** WARNING - COMPILER OPTIONS ARE NON DEFAULT
     INLINECOM {  }

STEP SUMMARY:      0.180 STARTUP
                   0.000 COMPILATION
                   0.230 EXECUTION
                   0.150 CLOSEDOWN
                   0.560 TOTAL SECONDS
```

```
*++++++++++++++++++++++++ SUMMARY REPORTS ++++++++++++++++++++++++

*++++++++++++++++++++ DEMAND SATISFACTION ++++++++++++++++++++++

PARAMETER TONSONT(U,I,K)    unit U's equipment (in 100 tons)
*                           delivered on time;
  TONSONT(U,I,K) $MOVEUE(U,I,K)
       = SUM( (A,E1,E2,E3,T),
            TONSUE.L(U,A,I,K,E1,E2,E3,T)
              $((ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24) LE RDD(U))
                     $DSETX(U,A,I,K,E1,E2,E3,T))
            );

PARAMETER TONSLATE(U,I,K)   unit U's equipment (in 100 tons)
*                           delivered late;
  TONSLATE(U,I,K) $MOVEUE(U,I,K)
       = SUM( (A,E1,E2,E3,T),
            TONSUE.L(U,A,I,K,E1,E2,E3,T)
              $((ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24) GT RDD(U))
                      $DSETX(U,A,I,K,E1,E2,E3,T))
            );


PARAMETER PAXONT(U,I,K)    number (in 100s) of unit U's troops
*                          airlifted on time;
  PAXONT(U,I,K) $MOVEPAX(U,I,K)
       = SUM( (A,E1,E2,E3,T),
            TPAX.L(U,A,I,K,E1,E2,E3,T)
              $((ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24) LE RDD(U))
                     $DSETX(U,A,I,K,E1,E2,E3,T))
            );

PARAMETER PAXLATE(U,I,K)    number (in 100s) of unit U's troops
*                           airlifted late;
  PAXLATE(U,I,K) $MOVEPAX(U,I,K)
       = SUM( (A,E1,E2,E3,T),
           TPAX.L(U,A,I,K,E1,E2,E3,T)
              $((ORD(T)+ROUND(CTTOK(A,I,K,E1,E2,E3)/24) GT RDD(U))
                     $DSETX(U,A,I,K,E1,E2,E3,T))
            );

OPTION TONSONT:2:0:3;
DISPLAY TONSONT;
OPTION TONSLATE:2:0:3;
DISPLAY TONSLATE;
OPTION UENOGO:2:0:3;
DISPLAY UENOGO.L;
OPTION PAXONT:2:0:3;
DISPLAY PAXONT;
OPTION PAXLATE:2:0:3;
DISPLAY PAXLATE;
OPTION PAXNOGO:2:0:3;
DISPLAY PAXNOGO.L;

*+++++++++++++++++ AIRCRAFT UTILIZATION RATE +++++++++++++++++++

PARAMETER ACTUALUR(A)   actual utilization rate (in hrs per day per
*                       aircraft);
  ACTUALUR(A) =
```

```
     ( SUM ( (U,I,K,E1,E2,E3,T) $DSETX(U,A,I,K,E1,E2,E3,T),
          X.L(U,A,I,K,E1,E2,E3,T) * FLTTIME(A,I,K,E1,E2,E3) ) +
       SUM ( (I,K,E1,E2,E3,T) $DSETY(A,I,K,E1,E2,E3,T),
          Y.L(A,I,K,E1,E2,E3,T) * FLTTIME(A,I,K,E1,E2,E3) ) ) * 100
    /  SUM ( T, ( CARD(T)+1-ORD(T) ) * SUPPLY(A,T) $SUPPLY(A,T) );
DISPLAY ACTUALUR;

*+++++++++++++++++++++++ MOG CONSUMPTION ++++++++++++++++++++++++

*  Reports the MOG consumption of an airfield.  If you set the MOG
*  efficiency factor to 0.9, and the percentage of MOG capacity
*  used, MOGUSED(AF,T), is 90, then it means that the airfield has
*  "MOGed" out; i.e., the airfield's aircraft handling capacity is
*  a binding constraint.

PARAMETER MOGUSED(AF,T)   percentage of MOG capacity used ;
  MOGUSED(AF,T) = (
  SUM ( (U,A,K,E1,E2,E3) $DSETX(U,A,AF,K,E1,E2,E3,T) ,
   X.L(U,A,AF,K,E1,E2,E3,T) * MOGREQ(AF,A) * GTIME(A,'ONLD') / 24 )
*  MOG utilization when used as an origin airfield (I)

  +
  SUM ( (U,A,I,K,E2,E3,TP) $(
    1$DSETX(U,A,I,K,AF,E2,E3,TP) AND
    1$(ORD(TP)+ROUND(CTTOE1(A,I,K,AF,E2,E3)/24) EQ ORD(T)) AND
    1$DIST(I,AF) AND
    1$(CTTOE1(A,I,K,AF,E2,E3) NE CTTOK(A,I,K,AF,E2,E3)) ),
   X.L(U,A,I,K,AF,E2,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )

+ SUM ( (A,I,K,E2,E3,TP) $(
    1$DSETY(A,I,K,AF,E2,E3,TP) AND
    1$(ORD(TP)+ROUND(RCTTOE1(A,I,K,AF,E2,E3)/24) EQ ORD(T)) AND
    1$DIST(AF,E2) AND
    1$(RCTTOE1(A,I,K,AF,E2,E3) NE RCTTOI(A,I,K,AF,E2,E3)) ),
    Y.L(A,I,K,AF,E2,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
*  MOG utilization when used as an E1 airfield

  +
  SUM ( (U,A,I,K,E1,E3,TP) $(
    1$DSETX(U,A,I,K,E1,AF,E3,TP) AND
    1$(ORD(TP)+ROUND(CTTOE2(A,I,K,E1,AF,E3)/24) EQ ORD(T)) AND
    1$DIST(E1,AF) AND
    1$(CTTOE2(A,I,K,E1,AF,E3) NE CTTOK(A,I,K,E1,AF,E3)) ),
   X.L(U,A,I,K,E1,AF,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )

+  SUM ( (A,I,K,E1,E3,TP) $(
    1$DSETY(A,I,K,E1,AF,E3,TP) AND
    1$(ORD(TP)+ROUND(RCTTOE2(A,I,K,E1,AF,E3)/24) EQ ORD(T)) AND
    1$DIST(AF,E3) AND
    1$(RCTTOE2(A,I,K,E1,AF,E3) NE RCTTOI(A,I,K,E1,AF,E3)) ),
    Y.L(A,I,K,E1,AF,E3,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
*  MOG utilization when used as an E2 airfield

  +
  SUM ( (U,A,I,K,E1,E2,TP) $(
    1$DSETX(U,A,I,K,E1,E2,AF,TP) AND
    1$(ORD(TP)+ROUND(CTTOE3(A,I,K,E1,E2,AF)/24) EQ ORD(T)) AND
    1$DIST(E2,AF) AND
    1$(CTTOE3(A,I,K,E1,E2,AF) NE CTTOK(A,I,K,E1,E2,AF)) ),
   X.L(U,A,I,K,E1,E2,AF,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
```

```
 + SUM ( (A,I,K,E1,E2,TP) $(
    1$DSETY(A,I,K,E1,E2,AF,TP) AND
    1$(ORD(TP)+ROUND(RCTTOE3(A,I,K,E1,E2,AF)/24) EQ ORD(T)) AND
    1$DIST(AF,K) AND
    1$(RCTTOE3(A,I,K,E1,E2,AF) NE RCTTOI(A,I,K,E1,E2,AF)) ),
    Y.L(A,I,K,E1,E2,AF,TP) * MOGREQ(AF,A) * GTIME(A,'ENR') / 24 )
 * MOG utilization when used as an E3 airfield

   +
   SUM ( (U,A,I,E1,E2,E3,TP) $(
    1$DSETX(U,A,I,AF,E1,E2,E3,TP) AND
    1$(ORD(TP)+ROUND(CTTOK(A,I,AF,E1,E2,E3)/24) EQ ORD(T)) ),
    X.L(U,A,I,AF,E1,E2,E3,TP)*MOGREQ(AF,A)*GTIME(A,'OFFLD') / 24) )
 * MOG utilization when used as a destination airfield (K)

    / MOGCAP(AF,'NB') * 100 ;

OPTION MOGUSED:2:0:4;
DISPLAY MOGUSED;

*++++++++++ AIRCRAFT ALLOCATION AND MISSION ASSIGNMENTS +++++++++

OPTION ALLOT:2:0:2;
DISPLAY ALLOT.L;
OPTION X:2:0:1;
DISPLAY X.L;
OPTION Y:2:0:1;
DISPLAY Y.L;
OPTION TONSUE:2:0:1;
DISPLAY TONSUE.L;
OPTION TPAX:2:0:1;
DISPLAY TPAX.L;
```

```
COMPILATION TIME     =        0.060 SECONDS        VERID AIX-00-064

----   1258 PARAMETER TONSONT        unit U's equipment (in 100 tons)
                                     delivered on time

UNITA.XDAT.FFTJ  79.02,  UNITB.TYFR.FFTJ   6.92,  UNITD.TMKH.FFTJ 114.94
UNITE.TYFR.UGZX  27.96,  UNITF.TMKH.UGZX 183.96,  UNITG.TYFR.UGZX   5.03
UNITH.XDAT.UGZX   3.01,  UNITL.TYFR.UGZX   4.91,  UNITM.TYFR.UGZX   3.24
UNITN.TYFR.UGZX   5.03,  UNITO.TYFR.PKVV   3.07,  UNITP.TYFR.PKVV   5.22
UNITQ.TMKH.PKVV   9.59,  UNITR.TMKH.UGZX  10.13,  UNITS.TMKH.UGZX  10.13
UNITT.XDAT.UGZX   4.78

----   1260 PARAMETER TONSLATE       unit U's equipment (in 100 tons)
                                     delivered late

UNITC.XDAT.FFTJ 42.35,   UNITF.TMKH.UGZX 54.31,   UNITH.XDAT.UGZX  7.12
UNITI.QFQE.UGZX  5.03,   UNITJ.XDAT.UGZX 10.13,   UNITK.TYFR.UGZX  5.03
UNITM.TYFR.UGZX  1.98,   UNITO.TYFR.PKVV  1.84,   UNITQ.TMKH.PKVV  0.54
UNITT.XDAT.UGZX  5.35

----   1262 VARIABLE  UENOGO.L      unit U's equipment (in 100 tons) that
                                     are not airlifted

UNITA.XDAT.FFTJ 107.75,  UNITC.XDAT.FFTJ  20.88,  UNITE.TYFR.UGZX 635.73
```

```
----    1264 PARAMETER PAXONT          number (in 100s) of unit U's troops
                                       airlifted on time

UNITA.XDAT.FFTJ 126.98,  UNITB.TYFR.FFTJ  13.84,  UNITC.XDAT.FFTJ  30.43
UNITD.TMKH.FFTJ  97.76,  UNITE.TYFR.UGZX 199.37,  UNITF.TMKH.UGZX 190.82
UNITG.TYFR.UGZX   3.92,  UNITH.XDAT.UGZX   8.46,  UNITI.QFQE.UGZX   3.92
UNITJ.XDAT.UGZX   4.35,  UNITK.TYFR.UGZX   3.92,  UNITL.TYFR.UGZX   4.74
UNITM.TYFR.UGZX   3.72,  UNITN.TYFR.UGZX   3.92,  UNITO.TYFR.PKVV   4.74
UNITP.TYFR.PKVV   3.72,  UNITQ.TMKH.PKVV   8.46,  UNITR.TMKH.UGZX   8.46
UNITS.TMKH.UGZX   8.46,  UNITT.XDAT.UGZX   8.46

----    1266 PARAMETER PAXLATE         number (in 100s) of unit U's troops
                                       airlifted late

UNITC.XDAT.FFTJ 22.16,    UNITJ.XDAT.UGZX  4.11

----    1268 VARIABLE  PAXNOGO.L       number (in 100s) of unit U's troops
                                       not airlifted

                    ( ALL        0.00 )

----    1279 PARAMETER ACTUALUR        actual utilization rate (in hrs per
                                       day per aircraft)

C5   9.32,    C17  9.33,    C141 3.05,    C130 3.79,    747P 1.36,
747C 3.28,    DC10 0.44

----    1352 PARAMETER MOGUSED         percentage of MOG capacity

QFQE.DAY2  19.48,  QFQE.DAY3  49.21,  QFQE.DAY4  54.40,  QFQE.DAY5  12.73
QFQE.DAY6  70.60,  QFQE.DAY7  58.74,  QFQE.DAY8  18.08,  QFQE.DAY9  74.27
QFQE.DAY11 90.00,  QFQE.DAY12 90.00,  QFQE.DAY13 90.00,  QFQE.DAY14 90.00
QFQE.DAY15 90.00,  QFQE.DAY16 90.00,  QFQE.DAY17 90.00,  QFQE.DAY18 90.00
QFQE.DAY19 90.00,  QFQE.DAY20 90.00,  QFQE.DAY21 90.00,  QFQE.DAY22 32.70
QFQE.DAY23 90.00,  QFQE.DAY24 90.00,  QFQE.DAY25 60.00,  QFQE.DAY26 90.00
QFQE.DAY27 90.00,  QFQE.DAY28 48.50,  QFQE.DAY29 34.84,  TMKH.DAY4  16.69
TMKH.DAY5   0.65,  TMKH.DAY6   8.94,  TMKH.DAY7  14.75,  TMKH.DAY11 32.07
TMKH.DAY12 13.83,  TMKH.DAY13 32.07,  TMKH.DAY14 32.07,  TMKH.DAY15 13.45
TMKH.DAY16 34.18,  TMKH.DAY17 32.07,  TMKH.DAY18 32.07,  TMKH.DAY19 32.07
TMKH.DAY20 30.99,  TMKH.DAY21 53.70,  TMKH.DAY22 48.70,  TMKH.DAY23  8.79
TMKH.DAY24 49.17,  TMKH.DAY25 30.50,  TMKH.DAY26 40.37,  TMKH.DAY27 44.79
TYFR.DAY1   7.55,  TYFR.DAY2   3.54,  TYFR.DAY5   3.55,  TYFR.DAY6  69.31
TYFR.DAY7  24.30,  TYFR.DAY8   9.58,  TYFR.DAY10  4.03,  TYFR.DAY11 76.35
TYFR.DAY12 82.42,  TYFR.DAY13 40.39,  TYFR.DAY14 29.24,  TYFR.DAY15 20.43
TYFR.DAY16 76.54,  TYFR.DAY17 73.65,  TYFR.DAY18 17.64,  TYFR.DAY19  9.57
TYFR.DAY20 16.64,  TYFR.DAY21 88.40,  TYFR.DAY22 51.13,  TYFR.DAY23 90.00
TYFR.DAY24 28.10,  TYFR.DAY25 14.93,  TYFR.DAY26 42.61,  TYFR.DAY27 29.97
XDAT.DAY1   5.04,  XDAT.DAY2   2.16,  XDAT.DAY3   0.51,  XDAT.DAY6  19.04
XDAT.DAY7  10.40,  XDAT.DAY8   5.43,  XDAT.DAY9   2.80,  XDAT.DAY10  0.82
XDAT.DAY11 42.20,  XDAT.DAY12  4.67,  XDAT.DAY13 17.88,  XDAT.DAY14  8.08
XDAT.DAY15 19.07,  XDAT.DAY16 38.13,  XDAT.DAY17 24.84,  XDAT.DAY19  7.83
XDAT.DAY20 31.30,  FFTJ.DAY7   9.00,  FFTJ.DAY8   4.84,  FFTJ.DAY9  10.61
FFTJ.DAY11  0.46,  FFTJ.DAY12 90.00,  FFTJ.DAY13 12.35,  FFTJ.DAY14 33.59
FFTJ.DAY15 16.27,  FFTJ.DAY16 42.10,  FFTJ.DAY17 90.00,  FFTJ.DAY18 49.68
FFTJ.DAY19  4.93,  FFTJ.DAY20 13.50,  FFTJ.DAY21 54.00,  FFTJ.DAY22 41.26
FFTJ.DAY23 75.31,  FFTJ.DAY24 20.10,  FFTJ.DAY25 90.00,  FFTJ.DAY26 54.77
FFTJ.DAY27 85.10,  FFTJ.DAY28 84.14,  UGZX.DAY1   4.69,  UGZX.DAY2  36.48
UGZX.DAY3   8.88,  UGZX.DAY4   2.09,  UGZX.DAY5  69.97,  UGZX.DAY6  78.78
UGZX.DAY7  90.00,  UGZX.DAY8  75.80,  UGZX.DAY9   2.36,  UGZX.DAY10  8.06
```

```
UGZX.DAY11 90.00,  UGZX.DAY12 90.00,  UGZX.DAY13 90.00,  UGZX.DAY14 90.00
UGZX.DAY15 90.00,  UGZX.DAY16 90.00,  UGZX.DAY17 90.00,  UGZX.DAY18 90.00
UGZX.DAY19 90.00,  UGZX.DAY20 90.00,  UGZX.DAY21 90.00,  UGZX.DAY22 90.00
UGZX.DAY26  5.23,  UGZX.DAY28 31.35,  PKVV.DAY5  90.00,  PKVV.DAY6  90.00
PKVV.DAY7  90.00,  PKVV.DAY8   3.28,  KNMD.DAY7   0.73,  KNMD.DAY18  3.00
KNMD.DAY19  6.00,  FXSB.DAY7   4.03,  FXSB.DAY8   7.50,  FXSB.DAY9   8.06
FXSB.DAY11  4.03,  WWYK.DAY13  4.69,  WWYK.DAY14 43.74,  WWYK.DAY15 16.34
WWYK.DAY17 53.02,  WWYK.DAY18 50.16,  WWYK.DAY19 50.01,  WWYK.DAY20 27.64
WWYK.DAY21 90.00,  WWYK.DAY22  9.37,  WWYK.DAY24 56.25,  WWYK.DAY25 26.96
NNGX.DAY6  11.45,  NNGX.DAY7  12.36,  NNGX.DAY8  11.45,  NNGX.DAY9   4.61
NNGX.DAY10  1.35,  NNGX.DAY11 25.63,  NNGX.DAY13 25.63,  NNGX.DAY14 10.09
NNGX.DAY15 18.75,  NNGX.DAY16 59.42,  NNGX.DAY17 43.68,  NNGX.DAY20 25.71
NNGX.DAY22 51.43,  UTKY.DAY7   4.61,  UTKY.DAY8   2.88,  UTKY.DAY10  1.35
UTKY.DAY13 25.71,  UTKY.DAY14 21.11,  UTKY.DAY15 25.71,  UTKY.DAY16 25.71
UTKY.DAY17 25.71,  UTKY.DAY20 25.71,  UTKY.DAY21 12.86,  ZNRE.DAY7   8.65
ZNRE.DAY8   8.02,  ZNRE.DAY9   6.45,  ZNRE.DAY10  0.94,  ZNRE.DAY11  3.22
ZNRE.DAY13 21.22,  ZNRE.DAY14 14.78,  ZNRE.DAY15 18.00,  ZNRE.DAY16 18.00
ZNRE.DAY17 27.00,  ZNRE.DAY18  9.00,  ZNRE.DAY19 18.00,  ZNRE.DAY20 27.00
ZNRE.DAY21 27.00,  HTDS.DAY7  20.01,  HTDS.DAY8  10.75,  HTDS.DAY9  26.72
HTDS.DAY11  3.14,  HTDS.DAY12 59.80,  HTDS.DAY18 90.00,  HTDS.DAY21 60.00
FGDC.DAY6  43.25,  FGDC.DAY7  40.08,  FGDC.DAY8  32.24,  FGDC.DAY9   4.71
FGDC.DAY10 16.12,  FGDC.DAY12 90.00,  FGDC.DAY13 90.00,  FGDC.DAY14 90.00
FGDC.DAY15 90.00,  FGDC.DAY16 90.00,  FGDC.DAY17 90.00,  FGDC.DAY18 90.00
FGDC.DAY19 90.00,  FGDC.DAY20 90.00,  FGDC.DAY21 90.00

----   1357 VARIABLE  ALLOT.L       new aircraft assets made available
                                     allotted to base (I).

C5  .TYFR.DAY1    1.44,    C5  .XDAT.DAY1    8.56
C5  .XDAT.DAY6   30.00,    C5  .XDAT.DAY11  40.00
C17 .TYFR.DAY1    2.00,    C17 .TYFR.DAY6    6.00
C17 .TYFR.DAY11   8.00,    C141.QFQE.DAY1    3.29
C141.QFQE.DAY6    6.17,    C141.TYFR.DAY1    5.02
C141.TYFR.DAY6   53.83,    C141.XDAT.DAY1   11.69
C141.XDAT.DAY11  80.00,    C130.TYFR.DAY1   20.00
C130.TYFR.DAY6   60.00,    C130.TYFR.DAY11  80.00
747P.TYFR.DAY6    6.51,    747P.TYFR.DAY11  30.00
747P.TYFR.DAY16  20.00,    747P.XDAT.DAY6    3.49
747C.QFQE.DAY6    2.68,    747C.TYFR.DAY6    1.19
747C.TYFR.DAY11   7.34,    747C.TYFR.DAY16   8.37
747C.XDAT.DAY6    1.13,    747C.XDAT.DAY11  17.66
747C.XDAT.DAY16  29.35,    DC10.TMKH.DAY11   7.10
DC10.TYFR.DAY11  17.90,    DC10.TYFR.DAY16   6.29
DC10.XDAT.DAY6    5.00,    DC10.XDAT.DAY16   9.67

----   1359 VARIABLE  X.L          number of airlift missions (aircraft)

UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY12  11.22
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY13   9.98
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY14   8.48
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY15  33.48
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY16   3.51
UNITA.747P.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY12   3.87
UNITA.747P.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY16  10.80
UNITA.747P.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY16  25.98
UNITA.747C.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY19  10.80
UNITA.747C.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY20  21.60
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY13  21.53
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY14   8.47
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY15  15.75
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UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY16   23.93
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY17    4.29
UNITA.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY17   22.73
UNITA.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY20   21.60
UNITA.DC10.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY17    9.67
UNITB.C130.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY16   26.37
UNITB.747C.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY18    3.05
UNITB.DC10.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY17    2.35
UNITB.DC10.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY19    3.95
UNITC.C5  .XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY11   40.00
UNITC.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY11   13.33
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY6     2.20
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY7     3.87
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY8     3.49
UNITC.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY10    0.37
UNITC.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY11   21.53
UNITC.DC10.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY6     5.00
UNITC.DC10.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY8     5.00
UNITD.C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY21   22.56
UNITD.C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY22    2.31
UNITD.C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY24   48.00
UNITD.C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY25   32.00
UNITD.C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY27   39.11
UNITD.C5  .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY22   23.13
UNITD.C17 .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY26   16.00
UNITD.C17 .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY22   16.00
UNITD.C141.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY23   30.02
UNITD.C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY24   37.33
UNITD.C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY25   17.08
UNITD.C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY26  100.00
UNITD.C130.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY22    3.93
UNITD.C130.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY27   93.12
UNITD.C130.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY21   31.98
UNITD.747C.TMKH.FFTJ.TMKH.TYFR.FFTJ.DAY22   23.63
UNITD.747C.TMKH.FFTJ.TMKH.TYFR.FFTJ.DAY26    6.51
UNITE.C17 .TYFR.UGZX.TYFR.TYFR.UGZX.DAY11    8.00
UNITE.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY12   53.63
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11   14.43
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY13   15.57
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY16   20.00
UNITE.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11    7.34
UNITE.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY16    5.32
UNITE.DC10.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11   17.90
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY11   37.32
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY12    0.60
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY13   37.32
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY14   37.32
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15   13.94
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY16   29.40
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17   37.32
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY18   37.32
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY19   37.32
UNITF.C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY20   25.44
UNITF.C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY21   32.00
UNITF.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY11    0.79
UNITF.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15    8.00
UNITF.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17    7.71
UNITF.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY19    8.00
UNITF.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY20    8.00
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY11    7.21
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UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY12   8.00
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY13   8.00
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY14   8.00
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY16   8.00
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY17   0.29
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY18   8.00
UNITF.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY21  18.96
UNITF.C130.TMKH.UGZX.TYFR.UGZX.UGZX.DAY20  57.21
UNITF.747P.TMKH.UGZX.TMKH.TYFR.UGZX.DAY12   3.68
UNITF.747C.TMKH.UGZX.TMKH.TYFR.UGZX.DAY12   8.47
UNITF.747C.TMKH.UGZX.TMKH.TYFR.UGZX.DAY16   8.58
UNITG.C5  .TYFR.UGZX.TYFR.TYFR.UGZX.DAY1    1.44
UNITG.C17 .TYFR.UGZX.TYFR.TYFR.UGZX.DAY1    2.00
UNITG.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY2    1.73
UNITG.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   20.00
UNITH.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY1    8.56
UNITH.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY6   14.28
UNITH.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY2    1.72
UNITH.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY3    2.22
UNITI.C141.QFQE.UGZX.TYFR.UGZX.UGZX.DAY2    3.29
UNITI.C141.QFQE.UGZX.TYFR.UGZX.UGZX.DAY6    6.17
UNITI.747C.QFQE.UGZX.TYFR.UGZX.UGZX.DAY6    2.68
UNITJ.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY6    8.82
UNITJ.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY2    7.75
UNITJ.747P.XDAT.UGZX.NNGX.TYFR.UGZX.DAY6    1.28
UNITJ.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY6    1.13
UNITJ.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7    2.70
UNITJ.747C.XDAT.UGZX.NNGX.HTDS.UGZX.DAY8    1.13
UNITK.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY2    3.29
UNITK.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   16.07
UNITL.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   11.31
UNITL.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6    1.48
UNITL.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6    1.19
UNITM.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   10.37
UNITM.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   13.12
UNITM.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6    1.16
UNITN.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   16.07
UNITN.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6    1.22
UNITO.C17 .TYFR.PKVV.TYFR.TYFR.PKVV.DAY6    6.00
UNITO.C130.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   12.24
UNITO.747P.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6    1.48
UNITP.C130.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   34.65
UNITP.747P.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6    1.16
UNITQ.C5  .TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    2.08
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    2.00
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY6    2.00
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY7    1.05
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY4   17.77
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY5    2.22
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY6    3.36
UNITQ.C130.TMKH.PKVV.QFQE.UGZX.UGZX.DAY4   20.00
UNITR.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY4    7.92
UNITR.C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY6    5.11
UNITR.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY6   11.25
UNITS.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY7    4.89
UNITS.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY7    4.95
UNITS.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY7   31.06
UNITT.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY7    6.89
UNITT.747P.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7    2.64
UNITT.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7    1.17
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UNITT.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY9    3.87
UNITT.747C.XDAT.UGZX.NNGX.HTDS.UGZX.DAY10   0.76

----   1361 VARIABLE  Y.L            number of type A aircraft recovered
C5  .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY26 39.11
C5  .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY12 34.64
C5  .TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY18  5.36
C5  .TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY23 48.00
C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY3  10.00
C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY9  37.92
C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15 24.90
C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY21 25.44
C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY23  9.22
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY5   3.03
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY6   4.89
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY12  2.68
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY15  4.50
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY20  5.15
C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY23 22.78
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY13 37.32
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY14 13.94
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY16 45.24
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY17 29.40
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY18 37.32
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY19 20.08
C5  .TMKH.UGZX.WWYK.UGZX.UGZX.DAY20 49.41
C5  .TMKH.PKVV.TYFR.UGZX.PKVV.DAY5   2.08
C17 .TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY24 16.00
C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY3   2.00
C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY8   4.95
C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY13  8.00
C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY11  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY14  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY15  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY16  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY18  8.00
C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY19  8.00
C17 .TMKH.UGZX.WWYK.UGZX.UGZX.DAY12  8.00
C17 .TMKH.UGZX.WWYK.UGZX.UGZX.DAY21 16.00
C17 .TMKH.PKVV.QFQE.UGZX.PKVV.DAY5   2.00
C17 .TMKH.PKVV.QFQE.UGZX.PKVV.DAY8   3.05
C17 .TMKH.PKVV.TYFR.UGZX.PKVV.DAY6   6.00
C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY23 27.18
C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY27 54.42
C141.TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY20 52.82
C141.TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY24 30.02
C141.TMKH.UGZX.QFQE.UGZX.UGZX.DAY3  17.77
C141.TMKH.UGZX.QFQE.UGZX.UGZX.DAY4   2.22
C141.TMKH.UGZX.QFQE.UGZX.UGZX.DAY6  27.89
C141.TMKH.UGZX.QFQE.UGZX.UGZX.DAY20 41.25
C141.TMKH.UGZX.QFQE.UGZX.UGZX.DAY22 27.24
C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY20 24.89
C141.TMKH.PKVV.QFQE.UGZX.PKVV.DAY5  17.77
C141.TMKH.PKVV.QFQE.UGZX.PKVV.DAY26  5.58
C130.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY18 22.45
C130.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY24 35.91
C130.TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY20  3.93
C130.TMKH.UGZX.QFQE.UGZX.UGZX.DAY3  20.00
C130.TMKH.UGZX.TYFR.UGZX.UGZX.DAY7  13.12
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C130.TMKH.UGZX.TYFR.UGZX.UGZX.DAY23 57.21
C130.TMKH.UGZX.WWYK.UGZX.UGZX.DAY17 53.63
C130.TMKH.PKVV.QFQE.UGZX.PKVV.DAY28 66.88
747P.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY11  3.41
747P.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY21 36.78
747P.TMKH.UGZX.QFQE.UGZX.UGZX.DAY20 23.22
747P.TMKH.UGZX.TYFR.UGZX.UGZX.DAY11  0.26
747P.XDAT.FFTJ.FXSB.ZNRE.FGDC.DAY7   2.20
747P.XDAT.FFTJ.FXSB.ZNRE.FGDC.DAY8   3.87
747P.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY12  0.07
747P.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY13  3.87
747P.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY6   3.87
747P.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY7   1.28
747P.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY13  5.39
747P.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY14  5.85
747P.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY15 21.60
747P.XDAT.PKVV.KNMD.ZNRE.FGDC.DAY6   2.64
747C.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY14  5.78
747C.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY23 23.63
747C.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY27  6.51
747C.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY11  0.37
747C.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY15  2.80
747C.TMKH.FFTJ.NNGX.FFTJ.FFTJ.DAY21 43.20
747C.TMKH.UGZX.QFQE.UGZX.UGZX.DAY11  8.10
747C.TMKH.UGZX.TYFR.UGZX.UGZX.DAY16  5.14
747C.TMKH.UGZX.TYFR.UGZX.UGZX.DAY17  8.58
747C.XDAT.FFTJ.KNMD.ZNRE.FGDC.DAY17 10.80
747C.XDAT.FFTJ.KNMD.ZNRE.FGDC.DAY18 21.60
747C.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY12 21.53
747C.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY14 15.75
747C.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY16 21.42
747C.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY19 21.60
747C.XDAT.FFTJ.UTKY.ZNRE.FGDC.DAY20 10.80
747C.XDAT.UGZX.FXSB.ZNRE.FGDC.DAY6   3.87
747C.XDAT.UGZX.FXSB.ZNRE.FGDC.DAY8   3.87
747C.XDAT.UGZX.FXSB.ZNRE.FGDC.DAY10  3.87
747C.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY7   1.13
747C.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY9   1.13
747C.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY13  8.47
747C.XDAT.UGZX.UTKY.ZNRE.FGDC.DAY16  0.18
DC10.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY18 12.01
DC10.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY12  5.00
DC10.TMKH.FFTJ.WWYK.FFTJ.FFTJ.DAY19  3.95
DC10.TMKH.UGZX.TYFR.UGZX.UGZX.DAY12 17.90
DC10.XDAT.FFTJ.FXSB.ZNRE.FGDC.DAY7   5.00

----   1363 VARIABLE  TONSUE.L      unit U's equipment (in 100 tons)
                                    airlifted

UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY12  1.26
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY13  1.12
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY14  0.95
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY15  3.76
UNITA.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY16  0.39
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY13 22.10
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY14  8.70
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY15 16.17
UNITA.747C.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY16 24.56
UNITB.C130.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY16  3.67
UNITB.747C.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY18  3.25
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UNITC.C5   .XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY11 19.93
UNITC.C141.XDAT.FFTJ.QFQE.FFTJ.FFTJ.DAY11  1.50
UNITC.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY10  0.35
UNITC.747C.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY11 20.58
UNITD.C5   .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY21 15.41
UNITD.C5   .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY24 32.79
UNITD.C5   .TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY25 21.86
UNITD.C5   .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY22 15.80
UNITD.C17  .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY22  4.51
UNITD.C130.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY22  0.47
UNITD.C130.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY21  2.25
UNITD.747C.TMKH.FFTJ.TMKH.TYFR.FFTJ.DAY22 21.84
UNITE.C17  .TYFR.UGZX.TYFR.TYFR.UGZX.DAY11  4.27
UNITE.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY12  8.43
UNITE.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11  8.85
UNITE.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY16  6.42
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY11 23.61
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY12  0.38
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY13 23.61
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY14 23.61
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15  8.82
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY16 18.60
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17 23.61
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY18 23.61
UNITF.C5   .TMKH.UGZX.QFQE.UGZX.UGZX.DAY19 24.68
UNITF.C5   .TMKH.UGZX.TYFR.UGZX.UGZX.DAY20 16.82
UNITF.C17  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY11  0.31
UNITF.C17  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15  3.16
UNITF.C17  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17  3.05
UNITF.C17  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY19  3.16
UNITF.C17  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY20  3.16
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY11  2.49
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY12  2.76
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY13  2.76
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY14  2.76
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY16  2.76
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY17  0.08
UNITF.C17  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY18  2.76
UNITF.C130.TMKH.UGZX.TYFR.UGZX.UGZX.DAY20  6.48
UNITF.747C.TMKH.UGZX.TMKH.TYFR.UGZX.DAY12  7.58
UNITF.747C.TMKH.UGZX.TMKH.TYFR.UGZX.DAY16  7.67
UNITG.C5   .TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   1.23
UNITG.C17  .TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   1.02
UNITG.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   2.78
UNITH.C5   .XDAT.UGZX.QFQE.UGZX.UGZX.DAY1   3.01
UNITH.C5   .XDAT.UGZX.QFQE.UGZX.UGZX.DAY6   7.12
UNITI.C141.QFQE.UGZX.TYFR.UGZX.UGZX.DAY6   1.93
UNITI.747C.QFQE.UGZX.TYFR.UGZX.UGZX.DAY6   3.10
UNITJ.C5   .XDAT.UGZX.QFQE.UGZX.UGZX.DAY6   4.39
UNITJ.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY6   1.31
UNITJ.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7   3.12
UNITJ.747C.XDAT.UGZX.NNGX.HTDS.UGZX.DAY8   1.31
UNITK.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   5.03
UNITL.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   3.54
UNITL.747C.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   1.37
UNITM.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   3.24
UNITM.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   1.98
UNITN.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   5.03
UNITO.C17  .TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   3.07
UNITO.C130.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   1.84
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UNITP.C130.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6    5.22
UNITQ.C5  .TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    1.62
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    1.02
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY6    1.02
UNITQ.C17 .TMKH.PKVV.QFQE.UGZX.UGZX.DAY7    0.54
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    3.29
UNITQ.C130.TMKH.PKVV.QFQE.UGZX.UGZX.DAY4    2.64
UNITR.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY4    6.16
UNITR.C5  .TMKH.UGZX.TYFR.UGZX.UGZX.DAY6    3.58
UNITR.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY6    0.38
UNITS.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY7    3.81
UNITS.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY7    1.75
UNITS.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY7    4.57
UNITT.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY7    3.43
UNITT.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7    1.35
UNITT.747C.XDAT.UGZX.NNGX.TYFR.UGZX.DAY9    4.47
UNITT.747C.XDAT.UGZX.NNGX.HTDS.UGZX.DAY10   0.88

----   1365 VARIABLE  TPAX.L        number (in 100s) of unit U's troops
                                    airlifted

UNITA.747P.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY12 11.56
UNITA.747P.XDAT.FFTJ.XDAT.ZNRE.FGDC.DAY16 32.27
UNITA.747P.XDAT.FFTJ.NNGX.TYFR.FFTJ.DAY16 83.15
UNITB.DC10.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY17  5.16
UNITB.DC10.TYFR.FFTJ.TYFR.TYFR.FFTJ.DAY19  8.68
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY6   7.05
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY7  12.38
UNITC.747P.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY8  11.16
UNITC.DC10.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY6  11.00
UNITC.DC10.XDAT.FFTJ.NNGX.HTDS.FFTJ.DAY8  11.00
UNITD.C17 .TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY22  8.64
UNITD.C141.TMKH.FFTJ.QFQE.FFTJ.FFTJ.DAY23 32.03
UNITD.C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY24 34.44
UNITD.C141.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY25 15.76
UNITD.C130.TMKH.FFTJ.TYFR.FFTJ.FFTJ.DAY21  6.89
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11 46.18
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY13 49.82
UNITE.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY16 64.00
UNITE.DC10.TYFR.UGZX.TYFR.TYFR.UGZX.DAY11 39.37
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY11 27.24
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY12  0.44
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY13 27.24
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY14 27.24
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY15 10.18
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY16 21.46
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY17 27.24
UNITF.C5  .TMKH.UGZX.QFQE.UGZX.UGZX.DAY18 27.24
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY11  1.62
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY12  1.80
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY13  1.80
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY14  1.80
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY16  1.80
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY17  0.16
UNITF.C17 .TMKH.UGZX.TYFR.UGZX.UGZX.DAY18  1.80
UNITF.747P.TMKH.UGZX.TMKH.TYFR.UGZX.DAY12 11.76
UNITG.C5  .TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   1.05
UNITG.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY2   2.06
UNITG.C130.TYFR.UGZX.TYFR.TYFR.UGZX.DAY1   0.81
UNITH.C5  .XDAT.UGZX.QFQE.UGZX.UGZX.DAY1   6.25
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UNITH.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY2   0.96
UNITH.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY3   1.25
UNITI.C141.QFQE.UGZX.TYFR.UGZX.UGZX.DAY2   3.92
UNITJ.C141.XDAT.UGZX.QFQE.UGZX.UGZX.DAY2   4.35
UNITJ.747P.XDAT.UGZX.NNGX.TYFR.UGZX.DAY6   4.11
UNITK.C141.TYFR.UGZX.TYFR.TYFR.UGZX.DAY2   3.92
UNITL.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   4.74
UNITM.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   3.72
UNITN.747P.TYFR.UGZX.TYFR.TYFR.UGZX.DAY6   3.92
UNITO.747P.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   4.74
UNITP.747P.TYFR.PKVV.TYFR.TYFR.PKVV.DAY6   3.72
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY4   2.50
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY5   2.37
UNITQ.C141.TMKH.PKVV.QFQE.UGZX.UGZX.DAY6   3.58
UNITR.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY6   8.46
UNITS.C17 .TMKH.UGZX.QFQE.UGZX.UGZX.DAY7   2.67
UNITS.C141.TMKH.UGZX.TYFR.UGZX.UGZX.DAY7   5.79
UNITT.747P.XDAT.UGZX.NNGX.TYFR.UGZX.DAY7   8.46


EXECUTION TIME      =      31.990 SECONDS        VERID AIX-00-064

USER: Operations Research Department                 G940405-1442AX-AIX
      Naval Postgraduate School

**** FILE SUMMARY

RESTART    /home/limt/final.g0?
INPUT      /home/limt/alrep.gms
OUTPUT     /home/limt/alrep.lst

STEP SUMMARY:     0.260 STARTUP
                  0.060 COMPILATION
                 31.990 EXECUTION
                  0.000 CLOSEDOWN
                 32.310 TOTAL SECONDS
```

## LIST OF REFERENCES


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2. Yost, K.A., "The Thruput Strategic Airlift Flow Optimization Model," 30 June 1994.

3. Brooke, A., Kendrick, D., and Meeraus, A., GAMS A User's Guide, The Scientific Press, 1992.

4. Killingsworth, P., and Melody, L., "CONOP Air Mobility Optimization Model," paper presented at the Mobility Optimization Meeting, Monterey, California, 6 July 1994.

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